SKAGIT RIVER
SALMON AND STEELHEAD FRY
STRANDING STUDIES

SEATTLE CITY LIGHT

Environmental Affairs Division

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EXECUTIVE SUMMARY

Introduction

Regulating river flow as a consequence of hydroelectric power generation may adversely affect some instream resources. One of these effects, the stranding of salmonid fry in potholes and on gravel bars as flows drop during a period of decreasing power generation, has been the subject of research on the Skagit River for more than 20 years (1969-89). The results from much of this past research were inconclusive; consequently, Seattle City Light embarked on a more definitive study in 1985. This study investigated pothole trapping and stranding during the spring of 1985, and gravel bar stranding during the summer of 1985 and spring of 1986.

The 1985 pothole trapping and stranding research strove to answer several major questions. How significant is the problem of pothole stranding during the spring months? Which physical and hydraulic factors influence pothole trapping and stranding? What is the recruitment and residence time of fry moving into potholes?

The gravel bar stranding studies conducted during the summer of 1985 and the spring of 1986 provided important insight that was necessary to answer several major questions. What are the measurable factors affecting gravel bar stranding of fry? What is the relationship of these factors to each other and to gravel bar stranding? How significant is the problem of gravel bar stranding during the spring and summer stranding seasons?

The study area was a 27 mile section of river between Gorge Powerhouse at Newhalem downstream to the confluence with the Sauk River at Rockport. Below the study reach, the Sauk River, an uncontrolled river system, is thought to moderate but not eliminate the effects of the upstream dam operation. The mean annual flow of the Skagit River at Marblemount is 4,450 cfs. The mean annual flow of the Sauk River is 4,375 cfs. The study area was divided into three distinct stream reaches. The upper reach started at Gorge Powerhouse and extended downstream ten miles to Copper Creek. The six-mile, middle reach extended down to the Cascade River at Marblemount, and the ten-mile lower reach ended at Rockport.

During the months of August-October and to a lesser extent in February and March, tributary inflows within the project area are typically at low discharge levels. During these two time periods, the flow in the upper Skagit River is largely influenced by flow releases from Seattle City Light's Gorge Powerhouse. From a hydrologic standpoint, these time periods are when potholes and gravel bars are most vulnerable to rapid dewatering due to SCL operations. During these time periods, the daily Skagit River flow fluctuations result primarily from operational releases from Gorge Powerhouse rather than from tributary inflow. A typical day of power generation at Gorge Powerhouse involves a large flow release in the early morning hours as the demand for power increases. This release is usually maintained until the late afternoon or early evening when power requirements begin to decline. This reduction in flow usually occurs during the dark hours of the day and is referred to as the downramping phase of daily operation. This reduction in flow dewaters gravel bars and drains potholes. The larger the amplitude of the downramp, the more gravel bar area dewatered and potholes drained. The faster the downramp rate, the faster gravel bars and potholes are dewatered. The downramping phase of power operation is what these studies focused on, since dewatering of potholes and gravel bars result in trapped and stranded fry and juvenile salmonids.

Downramping rates as measured just below the powerhouse at Newhalem typically vary from 1,000 to 5,000 cfs/hour. These ramping rates are equivalent to a stage change of .5 - 2.3 ft/hr at Newhalem and .4 - 1.7 ft/hr at Marblemount. Gorge Powerhouse is capable of passing a maximum of 7,200 cfs without spilling water over the dam. Typical generation releases range from 1,300 to 6,000 cfs.

Four species of Pacific salmon and steelhead trout are among the many fish species that inhabit the upper Skagit River study area. Chinook, pink, chum, coho, and steelhead fry and juveniles are all vulnerable to both gravel bar stranding and pothole trapping and stranding.

Study Approach

Carefully constructed study designs were developed for the 1985 spring pothole study and summer gravel bar stranding study, and the spring, 1986 gravel bar study. The study designs were developed to provide the data types and quantities needed to answer the questions identified above.

Pothole Study

The experimental design for the pothole trapping and stranding study was based on the objectives developed through discussions with Seattle City Light and the Skagit Standing Committee consisting of resource agencies and tribes. The conceptualization of the pothole stranding phenomenon viewed a pothole much like a unit of fishing gear. In order for it to trap fry, it must be in operation at the right depth and in the right place. If the trap is left undisturbed for some time and then closed in some manner (receding water) fry may be caught. The study was designed to examine the effects of multiple factors on pothole trapping and stranding. The factors incorporated into the study design consisted of those that were of particular interest and judged likely to affect pothole trapping and stranding significantly. The study design involved the selection of a set of potholes from which hydrologic, physical and biological data were collected after a downramp of predetermined amplitude, ramp rate, and flow history. Most of these one-day tests were conducted on the weekends when Seattle City Light could best satisfy the testing requirements. Factors potentially affecting pothole trapping and stranding were divided into three categories: physical and spatial characteristics of potholes, hydrological conditions of downramp events (ramp rate, amplitude, beginning flow, endflow), and factors affecting seasonal fry behavior and abundance.

Nine weekends of testing were prescribed. Each weekend consisted of two predetermined downramps. The experimental design matrix was balanced with respect to amplitude and ramp rate. Amplitudes of 1000, 2500, and 4000 cfs were used along with downramp rates of 1000 and 2000 cfs. The data collected for these tests were of two types: first, biological data regarding the number of fry trapped (live fry that were observed in a disconnected pothole) and stranded (fry that were dead as a result of pothole dewatering); and, second, physical/hydrological data including time of observation, pothole depth, stream gauge reading, water temperature, and connection/disconnection status of the pothole. During each test downramp, these data were collected repeatedly from each pothole until the unramping phase began. The data resulting from each test downramp were consolidated into a row of summary data for each pothole which represented an "observation" that was entered into a database for statistical analysis. The planned experimental design could not be completed because high tributary inflows in late spring prevented completion of some tests. Therefore, the anticipated analysis had to be modified to accommodate these changes. Two secondary investigations were performed in conjunction with the pothole trapping and stranding study. The first investigation was designed to evaluate the residency time of salmonid fry in potholes. The investigation was designed to answer several questions. Which species of fry are most likely to be trapped in potholes during the spring and summer/fall seasons? How long do salmonid fry remain in individual potholes? How do certain pothole characteristics such as depth, cover, and proximity to the river affect pothole residency time of salmonid fry? The second investigation evaluated fry trapping and stranding in potholes on the Sauk River. The underlying purpose of the latter study was to confirm, on an uncontrolled river, the presence of potholes and qualitatively estimate the magnitude of fry trapping and stranding.

Gravel Bar Studies

The studies of fry stranded on gravel bars were conducted during two separate seasons, the summer of 1985 and the spring of 1986. The temporal differences in fry species during the spring and summer determined the need for two separate study seasons.

The study design developed for the summer of 1985 called for consecutive day testing to stabilize fry density as much as possible during the study period. The tests consisted of eighteen, one-day downramping tests conducted in August. The testing parameters were: two levels of downramp amplitude fluctuations (2,000 and 4,000 cfs); and three levels of downramping rate (1,000, 5,000 cfs/hr. and a accelerated downramp rate). The experimental design was balanced with respect to these factors with each treatment combination repeated three times over the eighteen test dates. A total of 35 gravel bar sites were chosen for study. These sites were balanced with respect to site location (middle of lower reach), gravel bar slope (0-5%, 6-10%, >10%), and bar substrate size (<3" and >3" diameter). The downramps of these tests were completed during darkness. In addition to the primary treatment factors, the effect of day versus night downramping was studied. Four other daytime downramping tests were conducted during the same study period to determine any differential effects of nocturnal versus diurnal downramping.

During each downramping test, three sets of data were collected by field observers. The high and low waterlines were measured from predetermined reference points, stranded fry were counted, their precise location measured, and the species and total length of each fry stranded was recorded for each of the 35 gravel bar sites. The field data were used to form a database from which the analysis was conducted using a microcomputer.

The gravel bar study completed during the spring of 1986 used as a model the approach and design developed for the 1985 summer gravel bar study. The only changes between the two studies involved ramping rate and downramp endflow levels. The accelerated downramp rate was not used and two downramp ending flow levels (3,000 and 3,500 cfs. at Marblemount) were added to the study design. The study sites were re-surveyed, remarked, and used again with only minor modifications. A total of twenty-four downramping tests were conducted between March 13 and April 14, 1986. The collection of field data and analysis closely paralleled those used during the summer of 1985 study. Data analysis consisted of classical analysis of variance and t-tests on log-transformed data. The response variable in all analyses was the number of fry stranded per bar site per downramp event.

Another small-scale experiment was completed during the spring gravel bar stranding study to determine the "rate of fry recruitment" into potholes of different types and locations. The primary question to be answered by this experiment was to determine how quickly fry re-inhabit potholes that have gone dry.

Results

Potholes

Chinook, coho, chum, and pink fry, and steelhead juveniles were found trapped and/or stranded in potholes within the study area on the Skagit River. Most fry trapped in potholes during the spring season were chinook fry, with lesser numbers of coho and chum salmon. During the summer season coho and steelhead fry were the only fish species trapped in potholes. Residency time of chinook fry in potholes averaged 2.4 days, steelhead juveniles 1.6 days, and chum 0.5 days during the spring season. Coho spent an average of 1.4 days in potholes during both the spring and summer season. Steelhead fry spent an average of 1.6 days in potholes during the summer season.

There were a total of 232 potholes from which data was collected during the course of the study. Eighty-one percent of the potholes were located in the lower reach of the study area. Forty-one percent of these lower reach potholes trapped fry and twenty percent stranded fry. The average number of trapped fry per pothole ranged from 0-128 and the average stranded per pothole varied from 0-14 fry. The other nineteen percent of the study potholes were located in the middle reach and thirty percent of these potholes trapped fry and seven percent stranded fry. Average trapped fry numbers for individual potholes ranged from 0-137 and average stranded fry numbers ranged from 0-1.75 fry.

The pothole stranding process is composed of two principle stages: trapping which is defined as the capture of fry in a pool isolated from the main-channel flow; and mortality due to stranding usually caused by the dewatering of a pothole. A pothole must communicate or connect with the main channel flow before fry can be recruited and possibly trapped. Each pothole has its own specific connection flow at which point it hydrologically connects to the main channel flow. If this connection flow is not equalled or exceeded trapping is not possible. Similarly, for trapped fry to become stranded the pothole must dewater. The dewatering process is essentially controlled by the main channel flow. If the flow falls low enough after the pothole becomes disconnected the pothole will eventually dewater completely stranding all fry trapped within. The main channel flow required to dewater a pothole is called the pothole dryflow. Each pothole has its own individual dryflow.

A total of 890 observations were made of disconnected potholes. Each observation represents a pothole that had the opportunity to trap and/or strand fry. Most of the pothole observations (648 of 890) had not trapped or stranded fry. Two hundred forty-two of the observations had trapped and/or stranded fry. Of the 242 observations trapping or stranding fry, 176 observations trapped but did not strand fry, averaging 29.8 fry/observation. The remaining 66 observations both trapped and stranded fry, averaging 19 trapped and 5.96 stranded. These results show that many potholes do not trap or strand fry. Many of those that do, merely trap fry, especially if a minimal water depth is maintained. A very small percentage of all potholes actually stranded fry, of which there appears to be two types; potholes that strand the highest number of fry also had the lowest trapping totals. It seems that these potholes do not trap large numbers of fry but those that are trapped are usually stranded. Conversely, potholes that had the highest average trapped numbers stranded relatively few because they rarely went completely dry during typical power operations.

Approximately 50% of the study potholes had connection flows between 4,000 and 5,000 cfs as measured at the Marblemount gauge. Pothole dry flows ranged from 1,000 to 5,500 cfs, with the peak of the dry flow distribution between 3,000-4,500 cfs.

The original pothole study design was not completed as a result of weather and uncontrollable tributary inflows. Nevertheless, an analysis was conducted of the three hydrologic factors hypothesized to affect the trapping efficiency of potholes; ramping rate, downramp endtime, and flow history. The analysis suggested a lack of correlation between trapping and ramp rate. The results presented in this report and field experience suggest that fry trapping depends more upon pothole fry recruitment than escape opportunities. The notion of ramp rate as a measure of how fast the trap closes does not appear to be of importance.

Downramp endtimes did not appear to have any significant affect on the average trapped/pothole. This result suggests that time of day and more specifically day versus night downramping had no effect on the number of fry trapped per pothole.

Flow history, hours of stable flow prior to a downramp, was thought to have some influence on fry trapping. The results of the analysis indicate that the near-term flow history (a few hours before downramp) plays no part in the numbers of fry trapped. However, a body of studies and experience accumulated during these studies indicate that long-term flow history (type and number of previous downramp events) may play an important role in determining the number of fry trapped in potholes. The concept of pothole overflow was found to be of particular importance. Pothole overflow refers to the depth of water over a pothole prior to a downramp event. The beginning flow of a downramp determines individual pothole overflow levels. A definite relationship was demonstrated between the average number of fry trapped in potholes and pothole overflow levels. Within the range of tested beginning flows, fry trapping was highest when pothole overflow was lowest and decreased as pothole overflow increased.

Ladley (1986) studied recruitment of fry into potholes that connect daily to main channel flow. His results indicate that pothole recruitment rate was strongly influenced by downramp beginning flow (which controls pothole overflow) and the beginning flow history (beginning flows of preceding downramps). When beginning flows were repeatedly near the connection flows of his study potholes, fry recruitment into these potholes incrementally increased. However, when a high beginning flow followed a series of low beginning flows the fry recruitment did not increase. The high beginning flows may effectively flush fry out of potholes due to large pothole overflows and high current velocities. Conversely, when low beginning flows were repeated over and over again, fry could remain in potholes between downramps and other fry from the main channel could locate and recruit into these potholes.

Pothole stranding takes place only after fry have been trapped in a pothole. Most pothole-related mortality occurs when potholes containing fry go dry. The main-channel flow level generally determines which potholes will be dewatered. Each pothole dewaters at a specific main channel flow, which is called the dryflow. When the main channel flow drops to, or below a pothole's dry flow it is likely to dewater, stranding all fry within it. Once a fry is trapped inside a pothole it has two possible ultimate fates, death by stranding, or escape, when and if the pothole re-connects to main-channel flow.

The connection and dryflow for an individual pothole combined with the beginning and ending flow of a particular downramp determines whether that pothole will be disconnected or go dry. The amplitude of a downramp event determines how many of the potholes inside the study area will disconnect and go dry. The greater the amplitude the more potholes disconnected and dry and the more fry trapped and stranded.

Most rivers, whether flows are controlled by man or uncontrolled, have potholes associated with them. This study confirms what other researchers have already documented, which is, that salmonid fry become trapped and stranded in potholes on uncontrolled river systems. Two pothole surveys were conducted on the Sauk River, an uncontrolled river system, as part of these investigations. These surveys documented the existence of potholes and the presence of trapped fry in them. Within a fifteen mile reach, a total of 53 potholes were identified, 22 of which contained trapped fry. Chinook fry were the primary species trapped with lesser numbers of chum fry. Stranded fry were not observed in these potholes but it was apparent that stranding would occur if water levels continued to drop. The surveys on the Sauk River show that pothole trapping and presumably stranding is a natural occurrence on an uncontrolled river system. The major difference between controlled (peaking) and uncontrolled river systems is that water level fluctuations occur more frequently.

Summer/Fall Gravel Bar Stranding

From July through October each year there are primarily two species of salmonid fry, steelhead and coho, present in the study area. Both species were found stranded on gravel bars. Vulnerability to gravel bar stranding begins at emergence from gravel and continues until both species outmigrate from the Skagit River.

A total of 2,171 fry were observed stranded on gravel bars during the August 1-20 downramping test period. Virtually all of those stranded were steelhead fry with coho fry contributing less than one percent to the total number stranded. Clearly, steelhead fry are most vulnerable to gravel bar stranding during the summer/fall time period and coho, although present, are not commonly stranded on gravel bars. Species composition data from fry occupying gravel bar habitat shows that both steelhead and coho fry were stranded on gravel bars roughly in proportion to their respective densities. Coho represented 2.6% of the total fry found residing in gravel bar stranding habitat and steelhead contributed the remaining 97.4%. Because not many coho occupy gravel bar habitat they are not nearly as vulnerable to stranding as are steelhead fry, which is the predominate species found occupying gravel bar habitat.

Stranding of steelhead fry on gravel bars appears to be size dependent. Steelhead fry between 3.0-3.5 centimeters were the most vulnerable to gravel bar stranding followed by fry in the 3.5-4.0 centimeter range. Once fry size increases above 4.0 centimeters vulnerability declines rapidly. Because so few coho were stranded on gravel bars during the study it was not possible to determine if stranding is size dependent.

Gravel bar stranding of steelhead and coho begins in late July and ends in late September. Prior to late July, runoff from snowmelt is typically high and emergence of steelhead is still relatively low. After September, most of the steelhead fry have typically grown larger than 4.0 centimeters, above which they are much less vulnerable to gravel bar stranding. Before and after this time period stranding of both steelhead and coho very likely continues but at a much reduced level affecting a much smaller number of fry.

Analysis of variance tests using the factors amplitude, downramp rate, week, and gravel bar slope, substrate, and location all showed a significant effect on gravel bar stranding with the exception of downramping rate.

Stranding during a 4,000 cfs downramp amplitude was significantly higher than for a 2,000 cfs downramp amplitude. In fact, the 4,000 cfs amplitude consistently stranded more than twice the number of fry than the 2,000 cfs amplitude fluctuation. There was also a definite tendency for fry to become stranded towards the end of a downramping event. This tendency was stronger for a larger amplitude than for a small amplitude downramp.

Downramping Rate did not have a significant effect on gravel bar stranding of steelhead fry during the summer season.

Gravel bar slope showed a very clear relationship to stranding of fry on gravel bars. Gravel bars with slopes of less than 5% accounted for the majority of all stranding during the summer/fall season. The results of this analysis indicate that the amount of habitat dewatered is far more important to steelhead stranding than the rate of habitat dewatering within the ranges tested. Above a 5% slope the stranding rate decreases dramatically as gravel bar slope increases.

The gravel bar location, or more specifically, the distance between a gravel bar and the powerhouse plays an important role in the effect of a downramp on fry occupying gravel bar habitat. Fry stranding is much greater upstream, (closer to the downramping source) where the relative volume of water involved in the downramp is greater. The further downstream the gravel bar, the less stranding (if fry densities and gravel bar slopes are comparable) because of the dampening effect of tributary inflow and a hydrologic attenuation of the downramp.

Gravel bar substrate was determined to be a significant factor with smaller substrate (<3") generally stranding more than coarse (>3").

There was no measurable difference in steelhead fry stranding between daylight or darkness downramping during the summer/fall season. This result was both surprising and interesting because salmon fry are extremely sensitive to daylight downramping.

Many gravel bars have physical features such as logs, wood debris, large rocks, vegetation lines, and channel depressions. The results of this study showed, very convincingly, that the location of a stranded fry is not influenced by any of these physical gravel bar features.

Stranding locations were also evaluated to determine if the distribution of stranded fry is influenced by differing downramping rates. A random versus stratified distribution was apparent. A comparison of fry stranding distributions, resulting from 1,000 and 5,000 cfs/hr ramping rates, showed that there was no difference between fry distributions or number stranded. A constant rate of stranding was observed for both the 1,000 and 5,000 cfs downramping rates.

The effect of an accelerated downramping rate (starts slow and ends fast) was compared with these results. A stratified distribution resulted with less fry stranding in the first part of the downramp compared with the latter part. The first part of the accelerated downramp was conducted at a 500 cfs/hr rate followed by 5,000 cfs/hr. The rate of stranding on the 500 cfs/hr portion of the bar was lower than the stranding rates of either 1,000 or 5,000 cfs/hr. These results indicate that the rate of stranding may be reduced at 500 cfs/hr, whereas stranding rates are higher but constant between 1,000-5,000 cfs/hr.

Spring Gravel Bar Stranding

There were fry and juveniles of four salmonid species; chinook, chum, pink, and steelhead present in the Skagit River during the field portion of these studies. Each species is present in the study area for varying lengths of time during the spring study period. Every other year (odd years) pink salmon return to the Skagit River to spawn. After emerging from the gravel, pink and chum salmon fry remain in the river for only a short time. Chinook salmon fry will remain in the river for approximately ninety days and steelhead juveniles that have over-wintered will also be present in the river during the spring months.

A total of 513 salmon fry and steelhead juveniles were found stranded on gravel bars as a result of 23 formal gravel bar stranding tests that were conducted between March 14 and April 13, 1986. Nearly 63% of the fish stranded during this period were chinook fry, 30% were pink fry, 5% were chum fry, and the final 2.2% were steelhead juveniles. These findings clearly show that fry of all three salmon species and steelhead juveniles are susceptible to gravel bar stranding. Chinook and pink salmon fry were stranded in much higher numbers than chum and steelhead. This finding is understandable since chinook fry densities were much higher than any other species in main-channel (near-shore) habitat. Chinook accounted for 81% of the main-channel fry population and only 42% of the fry stranded on gravel bars in late March and 77% on gravel bars in early April. In contrast, pink salmon represented only 8.8% of the main-channel population in late March, compared with 45.4% of the stranded population for the same time period. In early April, pink fry accounted for a much smaller portion of the main-channel population at 1.7% but still represented nearly 19% of the stranded fry. Chum salmon responded similarly to pink salmon representing only 0.4% of the main-channel fry populations, but accounting for nearly 10% of the total fry stranded. Very few steelhead juveniles were stranded on gravel bars during the spring season. This was not surprising as the summer/fall gravel bar stranding data showed that once steelhead obtain a length of four centimeters they are not nearly as susceptible to gravel bar stranding. The analysis indicates that pink fry are 10-13 times more vulnerable than chinook fry. The same analysis shows that chum fry are 2 to as much as 43 times more vulnerable to stranding than chinook fry. Steelhead juveniles were found to be roughly one-half as vulnerable to stranding as chinook. Each species contributed varying numbers of fry to the total fry stranded. These contributions seem to be a function of fry abundance and the rate of stranding for each species. Even though chinook fry had a relatively low vulnerability to stranding, this species was still able to contribute the highest number to total stranding because of their overwhelming abundance in the shallow margins of the river where gravel bar stranding occurs. Pink and chum gravel bar stranding numbers were extremely high considering their relatively low abundance. This was most likely due to their high vulnerability rating.

The spring gravel bar stranding window of vulnerability is described as the time period when a specific species is most vulnerable to the effects of downramping. Chinook fry seem to be equally vulnerable during the majority of their freshwater lifestage (February-May). Chinook fry size was not an important factor (as for steelhead) because they outmigrate before significant growth is achieved. Pink and chum fry can be found in the study area between February and May but, unlike chinook, individual fry begin to outmigrate only a few days after emergence. During this short, post-emergence period, these two species were shown to be extremely vulnerable to gravel bar stranding. Like chinook, they do not have adequate time to grow during their brief stay in the study area. Because these two species do not grow appreciably before outmigrating, gravel bar stranding is not size-dependent.

Analysis of variance tests using the factors gravel bar slopes, downramping rate, and gravel bar substrate, and location all showed a significant effect on gravel bar stranding due to each factor. Downramp amplitude and ending flow tested non-significant.

Gravel bar slope, as expected, had a highly significant effect on gravel bar stranding. The average number of fry stranded on slopes less than 5% was more than eight times greater than the average for the remaining observations. Thirty-five percent of the gravel bars in the study area have slopes of less than 5% and these bars accounted for over 80% of all salmon fry stranding. The hydrologic effects on gravel bar stranding seem to be accentuated on gradually sloping bars (slope <5%).

There was a significant effect on stranding between the middle and lower river locations. As was the case with steelhead, there is a tendency for hydrologic effects on stranding to be greater toward the upper reaches.

Ramping rate tested significant under conditions which generally favor stranding (gentle slope, middle river, small substrate, and low amplitude). The higher ramping rate of 5,000 cfs/hr. stranded significantly more fry than the 1,000 cfs/hr rate.

Substrate tested significant, even more dramatically in test strata where stranding rates were high. However, there were many reverse interactions that made the behavior of this factor difficult to explain.

Amplitude tested non-significant. There was no significant effect due to the two amplitudes tested. Comparable numbers of fry were stranded using either a 2,000 or a 4,000 amplitude downramp. These results differed considerably from those reported for steelhead, where doubling of amplitude more than doubled stranding.

There was no significant effect due to the downramping ending flow. Two downramping ending flows were tested to determine if differential stranding rates would result from dewatering of gravel bar areas between 3,500 and 3,000 cfs as measured at the Marblemount gauge.

Fry stranding locations were evaluated to determine how this factor might be influenced by downramping rate, amplitude size, ending flow, and the type and location of a gravel bar's physical features. Low numbers of salmon fry stranding on the gravel bar sites studied prevented a conclusive evaluation of these factors on fry stranding locations.

A total of 42 gravel bar locations were identified inside the study area, representing 29,110 feet of gravel bar of various slope and substrate combinations. Forty-seven percent of the total gravel bar within the study area is located within lower river reach, 19% in the middle reach, and 35% in the upper reach. The majority of the lower reach is made up of bar slopes of less than 5% and substrate less than 3 inches in diameter. The middle and upper reaches show a more even distribution of the six different combinations of bar slope and substrate types.

Discussion

Pothole Trapping and Stranding

Pothole trapping and stranding involves two very distinct processes. The first process is when fry become trapped in a pothole. For a fry to become trapped it must not only be present at or near a pothole but the river stage must be lowered for a connected pothole to trap fry by becoming disconnected from the main-channel flow. Most recently emerged fry are present in waters-edge habitat that is shallower and typically has a slower velocity than the main-channel flow. In the Skagit River the waters-edge habitat moves dynamically on a daily basis as a result of weather and operation of the powerhouse at Newhalem. Fry are constantly subjected to stage changes that force them to move with the waterline if they wish to remain in waters-edge habitat.

At the beginning of any downramp event each pothole will either; begin the downramp disconnected from the main river channel flow, connected to the main river channel flow by only a few inches, or submerged by a large amount of main river channel flow. Each of these pothole-situations presents itself differently to fry. The pothole that begins the downramp disconnected from the main-channel flow will not effect free-swimming fry since there is no opportunity for trapping because the pothole will remain disconnected during the entire downramp event. The second pothole-situation represents a pothole that starts the downramp event connected to main-channel flow but is in or very near waters-edge habitat. Fry in this pothole when the downramp begins have very little time to escape from the pothole once it starts to disconnect from main-channel flow. The third pothole situation describes a pothole that is submerged by a substantial amount of water and likely begins the downramp away from waters-edge habitat. This pothole will remain connected to the main channel flow during a small amplitude downramp and will become disconnected during a large amplitude downramp event. If fry are to become trapped in this pothole they must first locate the pothole as the waterline recedes and secondly remain in the pothole as it disconnects from the main-channel flow. The fry trapping potential is thought to be much lower for this type of pothole compared to another that begins the downramp at waters-edge.

The second process involves the stranding of fry in potholes. Nearly all fry mortality in potholes occurs as a result of trapped fry becoming stranded as potholes dewater during a downramp event. Each pothole has a river flow at which it will go dry. When the river flow approaches a pothole's "dry flow" it is very likely that any fry trapped in the pothole will be stranded due to pothole dewatering. Once fry are trapped in a pothole they can not avoid stranding if the downramp event dewaters the pothole. Trapped fry can also fall victim to other factors such as predation and elevated water temperatures. While certainly a cause of some mortality, it is felt to be minor in terms of contribution to total pothole mortality. Water temperature is another possible source of pothole mortality. Water temperatures in potholes may reach harmful levels if prolonged exposure occurs when temperatures are high. Pothole temperature was monitored during the spring studies but never became a factor. During the summer months steelhead and coho fry trapped in potholes could fall victim to elevated water temperatures. Mortality of this type was never confirmed during these studies.

The factor that affects fry trapping in potholes the most is the beginning flow of a downramp event. The beginning flow determines the depth of water over a pothole while simultaneously determining the pothole's distance from waters-edge. Another important factor that is associated with beginning flow and fry trapping is the beginning flow history. If downramp beginning flows in the 4,500 to 5,500 cfs range are repeated in series, the number of fry trapped in potholes increases after each successive downramp. If the same process is repeated followed by a downramp with a higher level of beginning flow, the number of fry trapped remains moderately low. High beginning flow downramps may create rearing conditions that are unacceptable to fry. Conversely, low beginning flows encourage fry to seek out pothole habitat since these beginning flows coincide with a large number of pothole connection flows. When low beginning flows are repeated, fry numbers increase as fry already present take up residence between downramps and other fry become newly recruited. This process appears to be interrupted by a high downramp beginning flow which flushes fry from potholes, starting the process over again.

These studies showed that fry may remain in potholes for more than one downramp event or move back and forth between the pothole and the main channel between downramps. The study results also indicated that recruitment into an empty pothole (a pothole that had gone dry) can occur the first time the pothole re-connects to main-channel flow.

The magnitude of the pothole stranding problem was estimated by multiplying the highest level of stranding observed by the number of days when fry were most vulnerable during the spring season only. Within the limits of the study, the resulting index over-estimates stranding because it conservatively assumes that fry abundance remains constant (it does not) and that large amplitude downramps occur throughout the vulnerability period. This approach estimates that 9,180 salmon fry would be stranded during a typical spring vulnerability period within the middle and lower study reaches. There are several other sources of error that could not be dealt with such as predation on stranded fry and observer error. With these factors in mind it is possible to determine and understand within some limits of precision the magnitude of the pothole stranding problem. A similar index could not be produced for the July-September, steelhead and coho pothole trapping and stranding season because quantitative data were not collected.

Gravel Bar Stranding

When the river level rises as a result of precipitation, run-off, or power generation the result downstream is the same. The waters-edge moves up the gravel bar and fry that prefer this habitat move with it. This upramping process, in itself, does not create any problems for the fry since they can follow the waterline as it moves. If for some reason an individual fry decides not to follow the progress of the waterline, at worst it finds itself in habitat that is both deeper and faster then desired. This fry may become exhausted but in most circumstances this would not create a lethal situation since the fry can easily move to waters-edge habitat at any time. Conversely, downramping can lead to fry stranding if a fry can not adjust to changes in waters-edge. During a downramp event the waters-edge habitat moves at different speeds depending on the gravel bar slope, and the ramping rate of the downramp. The faster the ramping rate the quicker the waters-edge moves and the larger the amplitude fluctuation the farther a fry must move to avoid stranding. Many more fry are at risk during a downramp than actually become stranded. It appears only a very small percentage of those fry at risk actually become stranded. That is to say that the "average fry" makes the right decisions to avoid gravel bar stranding and that it is the odd fry that becomes stranded because it employs a different behavioral response (makes a wrong decision) to a downramp event. The results also show that gravel bar stranding is not a contagious behavior since most of the fry did not strand in groups.

The effect of the various testing parameters on gravelbar stranding between the spring and summer/fall seasons was consistent in some cases and not in others.

Amplitude - Before these studies were completed it was assumed that the amount of gravel bar stranding would be consistent with the amount of gravel bar dewatered. The larger the downramp amplitude the more fry stranded and the smaller the downramp the less fry stranded. This hypothesis was shown to be correct for the summer/fall season (steelhead fry) but did not hold for the spring season (salmon fry). During the spring season it appears that stranding is not influenced by downramp amplitude within the range of amplitudes tested, while steelhead fry during the summer/fall season stranded in proportion to the amount of gravel bar dewatered. It is not clear why stranding during both seasons would occur more frequently near the end of a downramping event especially a large amplitude event. It perhaps may be linked to some hydrologic changes that happen near the end of a downramp as river stage tries to reach an equilibrium.

Downramp Rate - The downramp rate determines how quickly a gravel bar will dewater which translates to the amount of time a fry has to avoid stranding. The higher the ramping rate the more quickly fry have to adjust to a descending waters-edge. This factor was thought to play a major role in determining the level of stranding. Ramping rates tested between 1,000 - 5,000 cfs had no significant effect on steelhead fry stranding. For steelhead it made little difference what ramping rate was used within this range. More interestingly, a closer examination of an accelerated ramping rate showed that fewer fry were stranded during the 500 cfs/hr phase than the 5,000 cfs/hr phase. It is possible that a threshold level is reached below which the rate of stranding is reduced and above which the rate of stranding remains relatively constant. If such a ramping rate exists our study indicates that it is somewhere between 500 and 1,000 cfs/hr. The same range of downramp rates were tested during the spring season.

Unlike steelhead, salmon fry demonstrated a definite response to differing levels of ramping rate. Significantly more salmon fry were stranded using a 5,000 cfs/hr downramp rate as compared with lower stranding levels from a 1,000 cfs/hr ramp rate. Ramping rates below 1,000 cfs/hr were not tested during the spring season. Because salmon fry responded differently to this factor than steelhead it would not be safe to assume that stranding rates would fall if downramping rates were dropped below 1,000 cfs/hr.

Gravel Bar Slope - The gravel bar slope was the factor that most significantly influenced gravel bar stranding during both seasons. The smaller the gravel bar slope the higher the stranding rate. Gravel bars with slopes of 0 - 5% represent approximately 30% of the total gravel bar area, yet accounted for more than 80% of the fry stranded during the summer/fall season.

The gravel bar slope combined with the downramp rate determines how fast a gravel bar will dewater. For any downramp rate, dewatering of gravel bar habitat will occur much more rapidly on a gravel bar with a gradual slope than a steep one. This is because the waterline must travel farther on a gradual slope than a steep one to reach the same stage. The rate of dewatering and the area dewatered increases as slope decreases. Because of this, hydrological effects are more exaggerated on gradual slope bars.

The slope of a gravel bar also determines the distance a fry must travel to avoid gravel bar stranding for a given downramp event. As the slope of a gravel bar increases the distance a fry must travel to escape stranding decreases. A fry positioned at the waterline during a downramp event will have to travel a much longer distance to escape stranding on a flat gravel bar than a steep gravel bar in roughly the same amount of time. The longer the distance traveled the greater the risk of stranding because of greater opportunity to become stranded. With higher ramping rates the fry must not only travel farther to escape, but must do it faster.

River Location - The location of the gravel bar on the river with respect to the source of the flow fluctuation has a strong bearing on the effect of any downramping event. The hydrologic effects of a given downramp event were always much stronger upstream than downstream. This relationship held true for both seasons. The location and amount of tributary and side stream inflow also affects the strength of a downramping event. A combination of distance and tributary inflow are capable of masking or moderating the effects of a downramp event. This relationship was well established throughout the results of the various testing factors. In almost all cases the stranding rate was higher in the middle stream reach where the relative volume of water involved in the event was greater compared to the lower reach where tributary inflow and distance combine to dampen the effects of downramping. The implications of these results could be extended to suggest that the un-studied upper reach may be more strongly affected than the middle reach due to its closer proximity to Gorge Powerhouse.

Ending Flow - Two downramp ending flows (as measured at Marblemount) of 3,00 and 3,500 cfs were not significantly different with respect to stranding under any testing condition.

The magnitude of the gravel bar stranding problem was estimated by multiplying the highest level of stranding observed from single downramps during the spring and summer/fall seasons by the number of days (each day represents a downramp) fry were most vulnerable. Within the limits of the study, the resulting indeces over-estimate gravel bar stranding because they conservatively assume that fry abundance remains constant (it does not) and that downramps producing the highest levels of stranding are repeatedly used throughout each of the two vulnerability periods. This analysis estimated that 46,695 fry were stranded on gravel bars during the summer/fall of 1985 and 19,512 fry during the spring of 1986. There were several other sources of error that could not be dealt with such as predation on stranded fry and observer error. With all of these factors in mind, these estimates make it possible to determine, within some limits of precision, the magnitude of gravel bar stranding problem.

Integration of Results

Common between the studies were three categories of evaluation factors; physical and spatial (eg., bar slope and substrate), biological factors (eg., fish species), and downramp factors (eg., ramp rate and amplitude). The general results of the combined studies were comparatively discussed in terms of these common evaluation factors. The physical and spatial factors share the common concept that they are not directly controlled or altered by Seattle City Light operations. These factors: pothole type and location, connection flows, substrate size, gravel bar slope, are all very dynamic in time. For example, the slope of a specific gravel bar can change after any high-water event. All of these factors would be extremely difficult to control or manipulate. Most of these factors play an extremely important role in fry trapping and stranding in potholes and fry stranding on gravel bars but would be difficult or in some cases impossible to alter to minimize trapping or stranding.

Biological factors, such as fish species and calendar date were shown to influence stranding but can not be realistically altered or controlled to minimize stranding. The results showed that certain fish species are present in the spring months and others are present during the summer/fall months. Some species were clearly more vulnerable to stranding than others. It is unlikely that any of these characteristics can be altered to minimize stranding. One of the most interesting results of the combined studies was drawn from an overall comparison of the spring and summer/fall gravel bar stranding rates. The summer/fall steelhead fry stranding rates were much higher than the spring salmon fry stranding rates. The only measurable differences between the two studies were the season, fry species, and densities. Because so many more salmon than steelhead spawn in the Skagit River, salmon fry densities are much higher than steelhead fry densities. If both salmon and steelhead fry are equally vulnerable to gravel bar stranding, the salmon fry stranding rates should be proportionally higher than the steelhead stranding rates. The opposite actually occurred indicating that steelhead fry are much more vulnerable to gravel bar stranding than are chinook fry. These results also suggest that a higher percentage of the steelhead fry population is affected by gravel bar stranding than salmon fry.

Downramp factors represent the final category of evaluation factors. These factors differ from the others because they are a function of hydropower operations and are subject to human control. This category of factors represents the only factor type that can be manipulated to influence the level of trapping and stranding. It is important to realize that modification of a factor may reduce pothole trapping while having a reverse effect on gravel bar stranding or perhaps spawning or red dewatering.

If a reduction of trapping and stranding is desired, each factors relative level of importance must be reevaluated based on each factors ability to influence trapping and stranding and ability to be manipulated. If the factor can be manipulated its overall level of importance is elevated above those that can not be altered. This assessment of factors focuses on those that are controllable and of importance to trapping and stranding. Other factors should be considered further only if there are significant interactions with controllable factors. Eight factors can be controlled with differing degrees of magnitude, difficulty and cost.

<u>Amplitude</u> - This factor has a greater influence over pothole trapping and stranding and gravel bar stranding in the summer/fall season than any other factor. If daily amplitude fluctuations were eliminated the majority of the

stranding losses would be eliminated without any consideration given to the other factors. Small background levels of stranding would still occur as a result of natural variations in flow levels. Amplitude elimination is not possible on the Skagit River, so it is important to understand how the magnitude and pattern of amplitude can be altered to reduce stranding.

To decrease the number of fry at risk to pothole and gravel bar stranding simultaneous, a reduced range of downramp amplitudes and higher beginning flows would have to be sustained to create high pothole overflows and reduced amounts of dewatered gravel bar area. Maximum results would be obtained by using this approach during both the spring and summer/fall stranding seasons or at least during the periods of peak vulnerability. Possible side-effects of this scenario are the possible reduction in suitable fry rearing habitat brought on by high beginning flows, and possible steelhead red dewatering in the spring because they may spawn higher because of higher flows. Long-term application of a downramping scenario like this may lead to the formation of a new set of potholes with higher connection and dry flows. This scenario may also impact power generation.

Ramping Rate - Ramping rate was shown to have no effect on trapping and stranding of fry in potholes. No net change in the number of fry trapped in potholes would result from a reduction in ramping rates, within the range tested. During the spring gravel bar stranding season it appears that if ramping rates did not exceed 1,000 cfs/hr, stranding would be reduced. If the same approach were applied to the summer/fall gravel bar stranding season there would be no measurable reduction in the number of fry stranded within the range of ramping rates tested. Evidence does suggest that if the ramping rate were lowered to 500 cfs/hr. a reduction in stranding would result. A possible side-effect of a 500 cfs/hr ramping rate might be an increase in fry recruitment to potholes. Fry will have more time and opportunity to locate and occupy potholes with the waterline receding so much slower.

Pothole Overflow - This factor appears to be a key factor in determining pothole trapping numbers during the spring season. If an emphasis is placed on reducing the number of fry trapped in potholes then downramps with beginning flows of 4,500 - 5,000 cfs should not be repeated in series to avoid the buildup of fry in potholes. If a series of low beginning flow downramps is unavoidable, it should be followed by a high beginning flow downramp to flush recruited fry from the potholes.

Downramp Time - The time of downramping was tested for its possible effects on gravel bar stranding of fry during both seasons. Daylight downramping during the spring season was shown to strand nearly seven times the number of fry as would the identical downramp conducted in darkness. During the summer/fall season there were no measurable effects. The effect of daylight and darkness downramping was not tested for pothole trapping.

Reductions in gravel bar stranding would be achieved by eliminating daylight downramping during the spring season. If daylight downramping is necessary during the spring months, the effects can be reduced by minimizing the response level of other downramping factors that influence stranding. During the summer season there is no evidence to support a similar elimination of daylight downramping.

Long-Term Flow History - This appears to be one of the key factors affecting the number of fry trapped in potholes, which ultimately determines the number of fry at risk to stranding. This factor can be manipulated to reduce the number of fry trapped and possibly stranded by following a series of low beginning flow downramps with a high beginning flow downramp. This sequence of downramps events allows potholes to recruit fry during the low beginning flow series and then to flush them out with a high beginning flow downramp. This method would be very effective prior to any downramp requiring a low beginning flow, which normally would dewater a large number of potholes.

Long-term flow history is thought to be of no importance to gravel bar stranding since fry are constantly adjusting to changes in waters-edge habitat caused by power generation and tributary inflow.

Short-Term Flow History - During the few hours preceding a downramp the evidence suggests that this factor is very little importance to pothole trapping or gravel bar stranding.

Downramp Ending Flow - This is a very important factor to pothole trapping and stranding because it determines the connection, disconnection, or dewatered status of a pothole at the completion of a downramp event. The downramp beginning flow and the amplitude are the two other factors that determine which pothole becomes disconnected from main-channel flow and which potholes will dewater.

Downramp ending flows were tested during the spring gravel bar stranding study and the results showed that the ending flow did not effect the number of fry stranded on gravel bars. It appears that the area dewatered on a gravel bar is of no importance in comparison to the type (slope, substrate, and location) of gravel bar dewatered.

Downramp Beginning Flow - This factor determines the upper limit of each downramp event and within the context of this study appears to be of importance to pothole trapping and stranding. This is because the beginning flow determines which potholes are connected and disconnected at the start of each downramp event. The beginning flow also determines the depth of the pothole overflow which was discovered to be a very important factor in determining the number of fry recruited and eventually trapped in potholes. Like downramp ending flow, this factor has no effect on gravel bar stranding.

The results of these studies clearly show that pothole trapping and stranding and gravel bar stranding contributes to a loss of anadromous production on controlled, and to a lesser extent, on uncontrolled river systems. The results of these studies indicate that Skagit River fry stranding in potholes and gravel bars can be minimized through the manipulation of several factors linked to power generation.

SECTION I

INTRODUCTION

1. GENERAL

Regulating river flow as a consequence of hydroelectric power generation may adversely affect some instream resources. One of these effects, the stranding of salmonid fry on gravel bars as flows drop during a period of decreasing power generation, has been the subject of research on the Skagit River for over 17 years. This research, sponsored and conducted by Seattle City Light's Environmental Affairs Division (SCL/EAD), concentrated for many years on qualitative evaluation of fry stranding on gravel bars. More recently, however, interest expanded to include a study of the role potholes, small to large depressions typically found along the riverbank, play in the capture and possible mortality of primarily chinook salmon (Onchorhynchus tshawytscha) and steelhead trout (Salmo gairdneri). Studies of pothole stranding begun in 1984 indicated some mortality occurred as a result of stranding in potholes as river flows dropped and potholes drained but results were inconclusive (Jones and Stokes and Associates, Inc., 1985). Consequently, SCL/EAD embarked on a more definitive study in 1985 that included both a review of earlier work and an expansion of the 1984 investigations.

The 1985 pothole trapping and stranding research strove to answer two questions. How significant is the problem of pothole stranding? And how can it be minimized? Additionally, past gravel bar stranding data were to be reviewed and a reanalysis made to identify any correlations that might exist between gravel bar stranding and other pertinent environmental variables. The field work during the spring of 1985 was partially confounded by high natural runoff from uncontrolled tributary waters entering the Skagit River downstream of Gorge Dam. At the same time there was a collective decision by the Skagit River Standing Committee (composed of joint resource agency representatives, tribes, and SCL/EAD) to shift emphasis away from pothole effects during the steelhead fry stranding study phase to one emphasizing the impacts of gravel bar stranding. This change in emphasis was accommodated by preparing a new study design aimed at investigating gravel bar stranding of steelhead and coho fry. This study proceeded as planned in August of 1985.

The relationship between salmonid fry behavior and the presence and influence of potholes on fry survival was also studied by David A. Troutt, a graduate student at the University of Washington's Cooperative Fisheries Research Unit. The work by Troutt has led to a better understanding of fry residency time in potholes with respect to behavioral and environmental relationships that may lead to pothole trapping and subsequent mortality. This understanding, in turn, could be used to sharply reduce pothole stranding as a source of mortality, should stranding play a significant role in fry population dynamics.

The final phase of field work was accomplished in the spring of 1986. The need for this additional work arose, in part, from studying the results of the reanalysis of historical gravel bar stranding data collected on the Skagit River since 1969. The reconstruction and reanalysis of these earlier data revealed that the selected multivariate analyses could not be made because of data and sampling limitations and the variability inherent in a series of studies that were not truly intended to be analyzed in combination. Through no fault of past researchers, the data contained several other weaknesses that prevented a conclusive analysis. These earlier data did provide a clear picture of how such an analysis might be performed, given a suitably designed and statistically sound sampling plan. Such a plan was prepared and successfully implemented in the spring of 1986.

The ultimate goal of this work was to study and command a better understanding of the pothole trapping and stranding and gravel bar stranding phenomena of the Upper Skagit River.

2. DESCRIPTION OF STUDY AREA

a. General

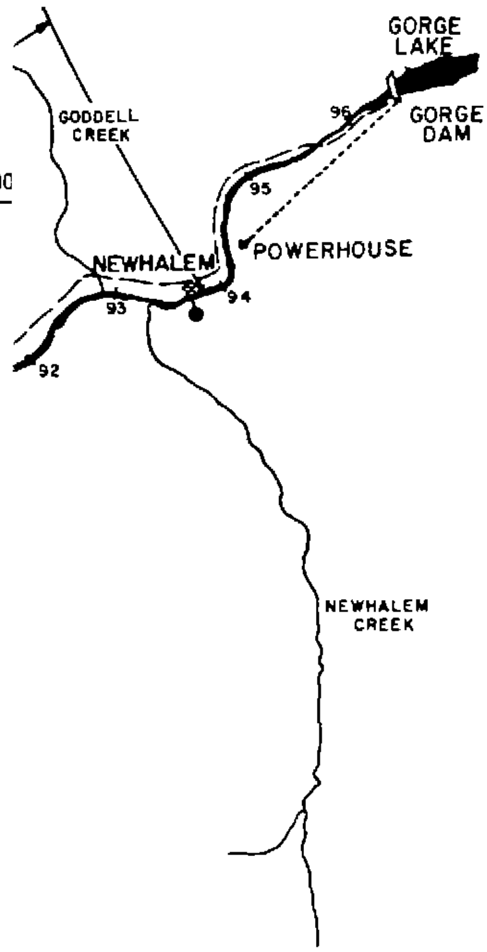
Since the first gravel bar stranding study in 1969 the river reach of most concern has been from Gorge Powerhouse at the Town of Newhalem downstream to Rockport at the mouth of the Sauk River, a distance of 26.7 miles (Figure 1). At Marblemount, which is 17 miles below Gorge Powerhouse, the Skagit River has a mean annual flow of 6,115 cfs. The Sauk River is the largest tributary of the Skagit River with a mean annual flow of 4,375 cfs near its confluence with the Skagit River at River Mile 67 (Figure 1). Below this downstream point the influence of the Sauk River discharge is thought to reduce the effects of the dam operations upstream. It is probably safe to assume that the effects of up- and downramping are masked downstream of the Sauk River, but this location does not represent the downstream extent of effects. However, for these studies, Rockport Bar at the mouth of the Sauk River represents the downstream boundary of the project area. Below this point no data were collected. As is explained later in greater detail, the project area was divided into three distinct stream reaches. (See Figure 1). The upper reach starts at Gorge Powerhouse (River Mile 94.2) and extends downstream to River Mile 84.0 just above Copper Creek. The middle reach extends downstream to the mouth of the Cascade River at River Mile 78.1, and the lower reach ends at Rockport, River Mile 67.5.

b. Flow Characteristics

During the months of August-October and to a lesser extent in February and March, tributary inflows within the project area are typically at low discharge levels. During these periods the flow in the Skagit River is largely influenced by flow releases from Seattle City Light's Gorge Powerhouse. From a hydrologic standpoint, these time periods are when potholes and gravel bars are most vulnerable to rapid dewatering due to SCL operations.

During the spring snow runoff months, April-July, the many tributaries entering the Skagit contribute heavily to the mainstem Skagit River flow. Besides the snowmelt that occurs each spring, heavy rain-events take place

STUDY AREA	MAP REF. NO
ROCKPORT BAR	1
WAYNE'S SWIM	2
TIN SHACK	3
BAD SPOT	5
EAGLE BAR	6
FORBIDDEN BAR	7
J.R. BAR	8
BEAVER ISLAND	9
STUMP HAVEN	10
MODEL POTHOLE	11
HOOPER'S SLOUGH	12
RICK'S SURPRISE	13
INACCESSABLE ISLAND	13
CARNAGE BAR	14
POWER BAR	15
DRY BAR	16
NORTH O'BRIANS FERRY	17
SECLUSION ISLAND	18
BIG EDDY	19
TEFLON BAR	20
MARBLEMOUNT SLOUGH	21
RAINIER POTHOLE	22
FUNGUS BAR	23
DIOBSUD CREEK	40
SAM'S BAR	24
MAPLE BAR	25
BACON CREEK	26
FACE BAR	27
OINK BAR	41
DRIFTWOOD BAR	28
MINIBAR	29
FLOWER POTHOLE	30
COPPER CREEK	31



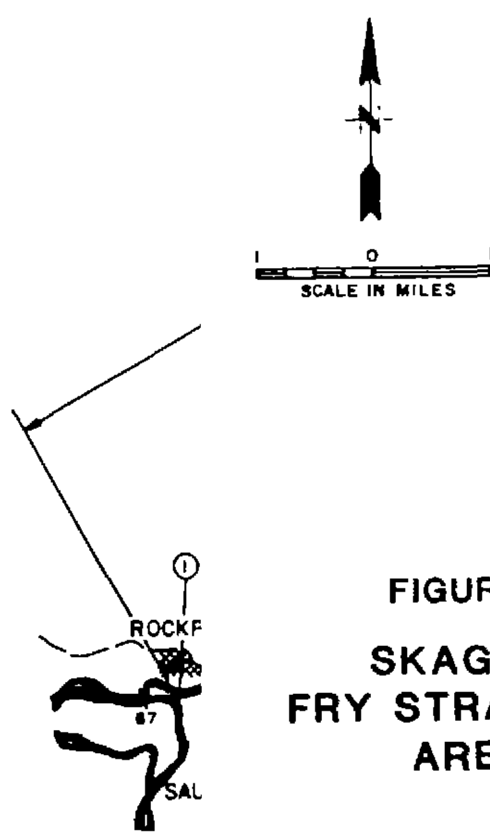


FIGURE 1

SKAGIT RIVER
FRY STRANDING STUDY
AREA MAP

somewhat unpredictably throughout the year but more frequently during the winter months. Snow runoff and rain events have the same effect on mainstem Skagit River flow by moderating the downstream effects of Gorge Powerhouse releases.

Daily Skagit River flow fluctuations result primarily from operational releases from Gorge Powerhouse rather than from tributary inflow. Normal operations typically involve larger flow releases in the early morning hours as the demand for power increases. This creates a positive upramp wave that moves downstream from the powerhouse as water is released at various ramping rates. The wave is undetectable to the human eye and the slope of the wave is determined by the rate of ramping. Once the necessary water release is reached, it is generally held at this higher flow until late afternoon or evening when power requirements begin to decline. At this time, flow released from the Gorge Powerhouse is reduced back to a much lower level, but does not fall below an agreed upon minimum instream flow release. The reduction in released flow from the Gorge Powerhouse is usually a daily occurrence that is mostly done at night. This phase of the daily operation is the "downramping phase" and creates a negative slope wave of water that moves downstream from the powerhouse. The relative size of the wave is controlled by the downramping rate used at the powerhouse. The faster the downramp rate the faster gravel bars and potholes become dewatered. This phase of power operation is what this study focused on, since dewatering of potholes and gravel bars result in trapped and stranded fry. Gorge Powerhouse has been in operation since 1919 and since that time SCL has assisted in the development of and has agreed to the use of specified operational constraints beyond those specified by their Federal license. In 1981 SCL entered into an interim flow agreement with the joint resource agencies which regulates the rate and magnitude of the flow fluctuation in the Skagit River.

Downramping rates as measured at Newhalem typically vary from 1,000 to 5,000 cfs/hour. Gorge Powerhouse can pass a maximum of 7,200 cfs without spilling water over the dam. Typical releases range from 1,300 to 6,000 cfs. There are no typical flow release patterns, but seasonally there is less demand for power generation during the warm summer months than during the winter months.

3. FISH RESOURCES

Four species of Pacific salmon and steelhead trout are among the many fish species that inhabit the upper Skagit River within the study area. Chinook, chum, and pink salmon are mainstem spawners while coho salmon spawn almost exclusively in tributaries to the Skagit River. Steelhead spawn in both the mainstem and tributaries of the upper Skagit River. Detailed life history information pertaining to Skagit River stocks is found in Graybill et al. (1979).

Chinook, pink, chum, coho, and steelhead fry are all potentially vulnerable to both gravel bar stranding and pothole trapping and stranding since all five of these species are present in the upper Skagit River. During the 1985 spring pothole trapping and stranding study and the 1986 spring gravel bar stranding study, the majority of the fry occupying vulnerable habitat were chinook and lesser numbers of pink, chum, and steelhead juveniles. Steelhead and coho fry were the only two fry species present during the 1985 summer gravel bar stranding study.

a. <u>Chinook Salmon</u>

Chinook salmon spawning peaks in September, with spawning activity from late August through October. Chinook fry emerge from February-April, with peak abundance in March and April. Chinook fry are found in all types of stream habitat (main-channel stream-edge, back-channels and sloughs, and potholes) during their freshwater rearing phase. Chinook typically outmigrate from April through July. Most of the chinook fry have moved out of the upper Skagit River by June.

b. <u>Pink Salmon</u>

Pink salmon spawning in the upper Skagit River normally takes place from mid-September through October. Pink fry are present in low numbers in both January and February, with peak abundance found in March and tailing off into April. Since pink salmon tend to spawn in odd numbered years, large numbers of their fry are present in habitat vulnerable to gravel bar and pothole stranding in even numbered years. Pink salmon fry, when present, are primarily found in main-channel habitat areas versus back-channel and pothole habitat. Pink fry spend very little time in the upper Skagit, with most fry outmigrating by May.

c. <u>Chum Salmon</u>

Chum salmon spawn in November and December in side channels and slow water main-channel areas of the upper Skagit River. Chum fry emerge in February-April, with peak abundance typically observed in April and May. Like the pink fry they are found primarily in main-channel habitat and typically have moved downstream out of the upper river area by June.

d. <u>Coho Salmon</u>

Coho spawn in tributary streams of the upper Skagit between October and January. Fry begin to emerge from the gravel in low numbers in February and March with most of the fry coming up from April-June. Unlike most of the other salmon fry, coho remain in the Skagit River for approximately 18 months. Most of the coho fry occupy pothole and back-slough areas and seem to avoid main-channel gravel bar habitat. Coho smolts outmigrate in the spring each year.

e. <u>Steelhead</u>

Much of the steelhead spawning takes place in the tributaries of the upper Skagit River (Phillips et al. 1980). Most of the spawning occurs in April and May. The fry resulting from each spawning cycle begin to emerge in early June, with peak abundance in August and September. Outmigrating smolts, which typically remain in freshwater for 24 months, leave the Skagit system during the spring months.

SECTION II

HYDROLOGY OF THE SKAGIT RIVER

1. GENERAL DESCRIPTION OF THE HYDROLOGY IN THE STUDY AREA

The Skagit River is typical of many larger western Washington rivers. It originates in the North Cascade Mountain Range north of the Canadian border and enters Puget Sound through a complex and expansive delta. As is often apparent in western Washington streams, the gradients in most upstream reaches of the Skagit River are much more steep than in reaches near the mouth. For this reason and others, the Skagit River was chosen as an excellent prospect for generation of hydroelectric power, leading to the development and operation of three high head dams. Ross Dam and Powerhouse is the largest in terms of power generation and reservoir volume and is located furthest upstream. Diablo Dam and Powerhouse is the middle power plant of the three and is located near the town of Diablo. The lowest dam and power plant is Gorge Dam. The dam and its detached Powerhouse are located near the Town of Newhalem. Operations of the three reservoir and generation systems are interconnected in a very complex and dynamic fashion.

The Ross Dam and Reservoir facility is mainly used as a storage, flood control, and power generating system. Diablo Dam and Reservoir is operated as a storage, flood control, and steady power generation system much like the operation of the Ross complex, but smaller in scale. The Gorge Dam and Powerhouse facility is operated differently than the other two powerhouses because it is frequently used to supply the peaking power demands of electricity customers.

2. FLOW CONDITIONS WITHIN THE STUDY REACH

Biological and physical effects of flow fluctuations downstream of the Gorge Powerhouse are the subjects of this study. The resulting flows below the powerhouse are a combination of mainstem Skagit River flows and tributary flows that enter the river below the system of reservoirs. Together these create the conditions that are experienced throughout the downstream reaches of the Skagit River. The raising and lowering of the river stage is the most noticeable condition and seems to be the driving force behind the stranding of many of the salmon and steelhead fry that is observed. Changes in stage are synonymous with changes in flow. The rate of change of flow and change of stage are governed by operations at the Gorge Powerhouse, weather, and streambed conditions and are termed the ramp rate. Ramp rates can be thought of as "upramps" or "downramps" depending on whether the flow rate is increasing or decreasing. Another flow characteristic that is related to the ramp rate and the flow is the amplitude of a particular "ramping" event. The amplitude of an event is the total change in flow from the beginning to the end of an event. The amplitude and the rate of change determine the magnitude of the ramping event.

The Skagit River below Gorge Powerhouse usually experiences a fluctuation in flow due to daily electricity generation. The characteristics of this fluctuation vary widely in terms of amplitude, ramp rate, base flow, and the flow rate at which the event stops. Figures A-1 through A-14 in Appendix A illustrate the shape of typical flow rate versus time hydrographs for the Skagit River before and during the study tests. These plots identify the flow rate at two different locations downstream of the powerhouse (Newhalem and Marblemount), including any increase in flow that occurs over the reach. The plots also illustrate the stream channel's frictional effect on the downramping event and how the event is attenuated both in magnitude of the peak flow rate and the speed at which the event passes the gaging station.

Following these hydrographs are three tables, one for each study, with the daily requested versus actual pothole and gravel bar stranding flow parameters (Tables A-15 to A-17). In nearly all cases, the actual flows closely paralleled the requested flows.

Two United States Geological Survey (USGS) gaging stations are located within the study reach and are used to verify flow information and duration from the powerhouse. The most upstream gage used is the Newhalem gage, USGS #1217800 near Newhalem. The other gage of interest is the Marblemount gage, USGS #12181000 near Marblemount. These two gages are separated by approximately 15 river miles. USGS primary flow records from the Newhalem and the Marblemount stream gages were used throughout the entire study to determine all flow-related parameters used in the analyses. The length of travel time (defined as time required for a downramp event to move from Newhalem to Marblemount) is important because it is a factor that affects the rate at which the stage of the river changes for any location along the river. Typically, travel times between Newhalem and Marblemount ranged from 2 to 3-1/2 hours, depending on several factors, such as the base flow rate of the river, the ramp rate of the event, precipitation conditions, the conditions of bank storage before and after an upramp event, the gradient of the river channel, and the occurrence or lack of hydraulic controls.

The base flow rate of the river is defined as the flow condition before or after an event. This flow condition is very close to a steady-state equilibrium, especially when compared to the dynamic flow conditions created during a ramping event. The flow can also be in a state of change. If the base flow is high and the riverbanks are full, then a positive wave of water caused by an increase in power generation would travel downstream faster than if the base flow were low. Likewise, if the base flow is high, a negative wave of water caused by decreasing power generation will travel downstream faster than if the base flow were low. In turn, a fast stage change (high ramp rate) will produce a fast moving waterline. Variations in travel time are also related to the effective smoothness of the river as related to the channel configuration and the depth of water in the channel.

The flow fluctuations used during the study attempted to exemplify the day-to-day flow regimes encountered on the Skagit River and, at the same time, satisfy the needs of the statistical design. The actual testing events used are described in Section III - Approach and Methodology.

The ramping rate (rate of flow change) also affects the travel time of a ramping event as depicted by a hydrograph of the event. A fast upramp or downramp will create a flow condition that is changing rapidly and will result in a waterline that moves much faster than for a slower ramping rate. This occurs because the speed at which the event's wave of water passes a certain location is influenced by how fast the flow stage changes.

Precipitation or snowmelt-caused increases in tributary inflow create a more dynamic or changing base flow which, in turn, affects the travel time of a given ramping event. These changes in base flow are not only unpredictable but tend to create dynamic flows over a longer period of time. The intensity and form of precipitation are factors that will affect the change in flow, depending on how fast the water from the precipitation enters the river.

The travel time of each flow event is also affected by the type of the river channel. Travel time is greatly affected by rivers that are lined with gravel substrate such as in the Skagit River. The substrate that is found on most of the study reach gravel bars is filled with many interstitial spaces that collect water. The ability of the stream channel to collect water is termed bank storage. An increase in flow, which increases the stage, will cause an infiltration of water into the porous gravel-lined streambank. Then, if the flow is reduced such as during a typical downramp event, there remains behind a large quantity of bank stored water that is gradually released back into the river as the stage falls away from the gravel bar. It is this process that causes the travel times of events to change in length and magnitude. A dry as opposed to a saturated gravel bar bank will slow the travel time and lessen the magnitude of an event until bank storage and the river stage reach an equilibrium. The process of bank storage produces very dynamic flow conditions that influence the extent and rate of river stage change and the depth and drainage of water in potholes adjacent to the river.

As described earlier, fluctuations in flow, both natural and man-caused, create changes in river stage which in turn changes the location of the waterline on any gravel bar. Generally, the waterline or waters-edge is an area of lower velocity which is a preferred habitat of newly emerged salmonid fry.

The physical area of waters-edge is always moving up and down the face of the gravel bar. The speed and distance that this waterline moves over the face of the gravel is affected by several factors. The factors influencing the speed of waterline change include the ramp rate of the powerhouse release, the river channel size, and shape and the slope of the gravel bar. The most obvious factor is the speed at which the river stage changes. This factor is controlled by dam operations or tributary inflow. The other factors (width, depth, channel roughness, and river gradient) are all physical characteristics which vary with location and time. Another important physical factor is the slope of the gravel bar. A flat-sloped gravel bar will produce a faster moving waterline for a given drop in stage than a steep-sloped gravel bar. Past gravel bar stranding researchers theorized that a waterline's receding speed was an important factor influencing fry stranding on gravel bars.

Potholes along the Skagit River, like gravel bars, are affected by the various rate of flow changes that occur as a result of dam operations and tributary inflows. The physical location, elevation, and the origin of the pothole determine whether a pothole will become connected to the river upon some upramp or determine the depth of the pothole when disconnected. The term "connection" is applied to a condition that occurs when the water in a pothole begins to touch the water in the main stem of the river. Sometimes flow will actually travel across the top of the pothole or it will simply touch the edge, thus allowing fish the opportunity of entering or exiting.

The conditions of bank storage will influence the depth and connectivity of a pothole to the river. If the river stage is high preceding a downramp event, those potholes that are high in elevation would be likely to connect if they were at or near the maximum river stage. As the river stage drops, potholes that are lower in elevation than the maximum river stage will begin to disconnect from the river. Those potholes that are left high on the bank will also begin to dewater or go dry as the water in bank storage drains out of the gravel bar. The pothole depth will vary depending on the amount of bank storage, amplitude, and length of the event. The difference in elevation between the water level in the pothole and the river and the porosity of the pothole bottom will govern how fast the pothole will drain. The actual connection-depth, or drying flow of a pothole is a very difficult and dynamic thing to determine and is everchanging.

SECTION III

OBJECTIVES AND APPROACH

There were four major areas of work:

1. 1985 Spring Pothole Trapping And Stranding Field Study

2. 1985 Summer/Fall Gravel Bar Stranding Field Study

3. 1986 Spring Gravel Bar Stranding Field Study

4. Reanalysis/Reconstruction Of Past Gravel Bar Stranding Data

Each of the four major study components had several associated subtasks. The approach and methodology for the four major study areas and subtasks follows in this section.

1. 1985 SPRING POTHOLE TRAPPING AND STRANDING STUDY

a. Objectives and General Description of Field Studies

The following list describes the objectives of this study which were developed and agreed upon by Seattle City Light, Skagit Standing Committee, and the R. W. Beck and Associates project team.

- Conduct field tests to determine the susceptibility of salmon fry and steelhead juveniles to pothole stranding.

- Determine the locations, physical characteristics, and flow characteristics of all potholes within the study area.

- Determine what physical and hydrologic factors influence pothole trapping and stranding of salmonid fry and juveniles.

- Determine the magnitude of pothole stranding by salmonid fry in the Skagit River between Rockport and Newhalem.

- Determine how pothole stranding by salmonid fry can be minimized within the Skagit River Study Area.

- Determine residence time of salmonid fry species moving into and out of potholes.

To meet these objectives, a well conceived study design was developed to provide the data types and quantities needed to answer these questions. In general, the field studies were implemented to collect biological, hydrologic, and physical data relating to a series of pothole trapping and stranding tests conducted between February 23 and May 16, 1985. Pothole data were collected from 24 distinct pothole areas and 239 individual potholes. A subset of these potholes was chosen to be monitored on a daily basis throughout the field study period. These potholes were chosen because they trapped or stranded fry during the Jones and Stokes, Inc. 1984 pothole study. In addition to these potholes, another series of potholes was chosen at random to represent the remainder of the pothole population not having a history of trapping or stranding fry. These random potholes were changed for each pothole test. Pothole testing was attempted on every weekend from February 23 to May 16. On several occasions weather-caused high water events masked the experimental requirements of a selected amplitude fluctuation and downramping rate which prevented using these data in the analysis. In all, 13 tests were completed without complications. The testing parameters were three levels of downramping amplitude fluctuations (1,000, 2,500, and 4,000 cfs) and two levels of ramping rate (1,000 and 2,000 cfs/hour). The flows preceding these test weekends were uncontrolled except for March 9 and 30 and May 15 when flow releases from Gorge Powerhouse were held constant for 24 hours prior to the test downramp. Table 1 displays the test types, by date for the spring 1985 pothole fry stranding studies. The testing schedule was structured so that the two testing variables were balanced with respect to time and replication. The original study design called for a set of 16 test days; due to weather constraints only 13 of the required tests were completed which left an incomplete and unbalanced statistical design.

(1) Study Design

The experimental design used for the pothole trapping and stranding study in the spring of 1985 was based on the study objectives developed through discussions with Seattle City Light staff and the Skagit Standing Committee. The pothole study conducted by Jones and Stokes, Inc. in 1984 was closely reviewed prior to completion of the study design. The factors incorporated into the study design consisted of those that were of particular interest and those that were judged likely to affect pothole trapping and stranding significantly.

The study design involved the selection of a set of potholes from which hydrologic, physical and biological data were collected after a downramp of predetermined amplitude, ramp rate, and flow history. The majority of these one-day tests were conducted on the weekends when Seattle City Light could best satisfy the testing requirements controlled by dam operation.

The potholes selected for mandatory observation were those having a history (Jones and Stokes, Inc., 1984) of trapping and/or stranding fry. These potholes were monitored during each test to determine how they responded, as measured by numbers trapped and stranded, to changes in amplitude and ramping rate changes. An additional set of potholes, from those without a history of trapping or stranding, was selected at random prior to each test conducted. The same data were collected from these potholes. The study design balanced the three levels of amplitude and two levels of ramping rate over the 12 weekend sampling period.

Factors affecting pothole stranding were divided into three categories. Pothole characteristics describe the physical features and location of the

TABLE 1

TEST TYPES BY DATE

SPRING 1985 POTHOLE SALMON STRANDING STUDY

DATE	TEST NO.	-----EVENT DESCRIPTION----- AMP	RAMP
FEBRUARY 23, 1985	1	A2	R1
MARCH 2	2	A1	R2
MARCH 3	3	A2	R2
MARCH 9	4	A3	R1
MARCH 10	5	A3	R1
MARCH 16	6	A2	R1
MARCH 17	7	A1	R2
MARCH 23	8	A3	R2
MARCH 24	9	A2	R2
MARCH 30	10	A2	R2
MARCH 31	11	A3	R2
APRIL 6	12	A1	R1
APRIL 7	13	A1	R1
MAY 15	14	A1	R2
MAY 16	15	A3	R2

Amplitude: A1 = 1000 cfs
A2 = 2500 cfs
A3 = 4000 cfs

Ramp Rate: R1 = 1000 cfs/hr
R2 = 2000 cfs/hr

Note: In general, all weekend tests were preceded by no specific amplitudinal or ramping changes, except March 9, March 30, and May 15 were specifically held at a constant flow rate with no change in amplitude for 24 hours.

potholes. They include factors such as cover, substrate, depth, elevation (measured by connectivity flow) drainage (measured as dry flow) and trapping and stranding history.

The second category of factors describe the hydrological conditions of a downramping event such as ramp rate, amplitude, beginning flow, end flow, and time of day.

The third category includes factors which affect seasonal fry behavior and abundance in the study area. The major factors here are time of year and annual fry abundance.

All three of these categories were considered in the development of the experimental design. A study constraint inherited from previous studies was that tests should occur on weekends. The principal reasons quoted for this constraint were that some spacing between tests was needed to make them independent of one another and also the cost of testing was less on weekends (in terms of hydroelectric generation). This constraint had the unfortunate consequence of extending the test period over a long period of time. Since time was identified as a critical variable, the effects of changing fry densities and size was to be compensated for by dividing the study into three month-long time strata for experimental design purposes.

Given the objectives stated above, it was judged necessary to make as many observations of pothole trapping and stranding as possible. To accomplish this, a probability sample among the identified potholes was selected by ranking them (based on the 1984 observations) in terms of stranding and trapping. The 50 potholes selected were responsible for 100% of all stranding and 70% of all trapping in 1984.

The remaining potholes were classified by cover (2 levels) and substrate (2 levels) and for each downramping test an additional number of potholes was drawn at random from each stratum. The actual number of random potholes surveyed after each test varied depending upon logistics.

For the analysis it was necessary to use data from potholes connected to the main-channel flow at the beginning of the downramp event and subsequently disconnected as flow was reduced. Consequently, potholes with connectivity flows exceeding the beginning flow of a test were excluded (some of this elimination occurred prior to the tests and some was done in a later data editing phase). This restriction was necessary so that fry trapped from earlier downramp events with higher beginning flows would not be confused with fry actually trapped by the experimental downramp. It should be noted that data was collected from potholes with connections flows higher than the actual beginning flow, but this data was eliminated prior to the analysis since it did not reflect the outcome of the experimental downramp but rather an earlier downramp.

The conceptualization of the pothole stranding phenomenon viewed a pothole much like a unit of fishing gear. In order for it to trap fry, it must be in operation at the right depth in the right place. Now if the trap is left undisturbed for a while and then closed in some manner (by the receding water) fry may be caught. The study was thus designed to examine the effects of downramp rate and flow history (hydrology on day preceding test).

Table 2 shows the prescribed test conditions for 9 weekends of testing. The rows represent three levels of time separated by one weekend. As the study progressed, it became clear that this spare weekend was needed to provide SCL sufficient flexibility and to deal with unpredictable tributary flow conditions.

The design matrix is balanced with respect to amplitude and ramp rate. The amplitude sequence between Tuesday and Saturday tests are never repeated.

Plus signs in Table 2 indicate the six tests that were completed as prescribed. Due to adverse weather conditions, the study could not be completed as designed.

(2) <u>Reconnaissance of Potholes</u>

Prior to the start of any pothole trapping and stranding tests the individual potholes had to be identified by boat survey from Newhalem downstream to Rockport. At each pothole area (typically a gravel bar containing a number of different potholes), the individual potholes were located, marked with a coded flag, and a rebar with fiberglass metric tape was installed in almost all potholes so that pothole water depth could be monitored. At each pothole area a stream channel staff gage was installed to monitor changes in river stage. Each pothole area was mapped to identify location and general size of each pothole. (See Appendix B). The potholes surveyed during this reconnaissance described the "pool" of potholes that were selected from for further pothole testing.

(3) <u>Pothole Trapping and Stranding Tests</u>

The data collected for these tests described above were of two types: first, biological data regarding the number of fry trapped (live fry that were observed in a disconnected pothole), and stranded (fry that were dead as a result of pothole draining, or extreme water temperatures); and second, physical/hydrologic data including time of observation, pothole depth, stream gage reading, water temperature, and connection/disconnection status of the pothole. These data were collected repeatedly for each pothole from when the observer arrived on the bar in the early morning through the early portion of the ensuing upramp. Appendix C contains the field data forms and the data collection procedures manual used by the observers when collecting pothole data. Each observer was assigned a pothole area containing one or more pothole(s) that he or she was responsible for. At the end of each test day, the data collected from each bar site was summarized onto one sheet (see summary sheet in Appendix C). The summary sheet had one entry per test day for each pothole observed. The summary data for each pothole follow:

TABLE 2

SPRING 1985 SALMON FRY POTHOLE TRAPPING AND STRANDING IN POTHOLES STUDY DESIGN

	Week 1 (2/23-2/24)	Week 2 ⊕ (3/2-3/3)	Week 3 ⊕ (3/9-3/10)	Week 4 (3/16-3/17)
Thursday Noon - Friday Night	*	*	A0	Monthly
Friday Night - Saturday Dawn	A2,R1	A1,R2	A3,R1	Make-up
Saturday Night - Sunday Dawn	A1,R1	A2,R2	A3,R1	Test
	Week 5 ⊕ (3/23-3/24)	**Week 6 ⊕ (3/30-3/31)**	**Week 7 ⊕ (4\6-4/7)**	**Week 8 (4/13-4/14)**
Thursday Noon - Friday Night	A0	*	*	Monthly
Friday Night - Saturday Dawn	A2,R2	A1,R1	A3,R2	Make-up
Saturday Night - Sunday Dawn	A3,R2	A1,R1	A2,R2	Test
	Week 9 (4/20-4/21)	**Week 10 ⊕ (4/27-4/28)**	**Week 11 (5/4-5/5)**	**Week 12 (5/11-5/12)**
Thursday Noon - Friday Night	*	A0	*	Monthly
Friday Night - Saturday Dawn	A2,R1	A1,R2	A3,R1	Make-up
Saturday Night - Sunday Dawn	A2,R1	A3,R2	A1,R1	Test

Amplitude CFS	Ramp Rate CFS/Hr	*
A0 = 0(±100)	R1 = 1000(±100)	No Preferred
A1 = 1000(±100)	R2 = 2000 or more (±200)	Amplitude or Rate
A2 = 2500(±250)		
A3 = 4000(±400)		

General

- After the initial downramp event, flow will be brought back up to previous 24-hour high level immediately following observations.
- Flows should be adjusted upward only to the extent needed to achieve the prescribed amplitude.
- Weeks 4, 8, and 12 may be shifted in front of any of the preceding three weeks.

⊕ The plus sign indicates tests were completed as prescribed (although some of these did not occur on the dates indicated)

- test date
- observer
- weather code
- pothole site
- pothole number
- fry trapped
- fry stranded
- pothole depth (min/max)

The summary data formed part of the database used to conduct the analysis.

(4) Data Processing and Analysis

The data from the field forms were entered onto a microcomputer using the R-Base 5000 software program. Detailed data processing algorithms are available upon request. All analysis and data processing was done on microcomputers (IBM compatible). All data currently reside on R-Base 5000 files. The statistical analyses were performed using a software package called CRISP.

CRISP is an interactive statistical package used for database manipulation, data transformation, and a number of standard statistical analyses; such as, ANOVA, multiple regression, principal components, t-tests, and several non-parametric tests. CRISP also allows the user to display data in tabular and graphic form.

Because the planned experimental design could not be completed the anticipated analysis had to be modified to accommodate these changes. The original intent of the statistical analysis approach involved the use of ANOVA to examine the effect of ramp rate and flow history on trapping and stranding in a representative set of potholes with a history of fry trapping and stranding. Due to the collapse of our experimental design, we were unable to examine the most important hydrological factors affecting pothole stranding.

b. Study Subtask Descriptions of Purpose and Approach

(1) Pothole Connection and Dry Flow Determinations

(a) Purpose

Potholes are capable of trapping and stranding fry only if they become connected to main-channel flow which provides the opportunity fry need to enter pothole influenced habitat. In general, potholes range in size from 1 to 50 feet in length or diameter. The larger the pothole area, the greater the potential trapping area. Once fry become trapped inside a particular pothole, several different situations may develop depending on the pothole type. From a physical standpoint, there are four basic pothole types:

- small/shallow
- small/deep
- large/shallow
- large/deep

Typically, the river flow fluctuates daily as a result of power generation. Depending on pothole type, a trapped fry will generally be subjected to the following situations. With a modest flow fluctuation, a small, shallow pothole will be mostly or completely dewatered. The same situation results in a large/shallow pothole because wetted perimeter dewatering is a function of pothole depth and bank gradient. With a large/shallow pothole more wetted perimeter is dewatered and, since the trapping area is larger, even more fry are potentially at risk to stranding. In deep potholes, both large and small, the risk of stranding is greatly reduced since much larger flow fluctuations are required to dewater and dry these pothole types. One of the primary responsibilities of the pothole studies was to document the "connection" and "dry" flows associated with each pothole. The connection flow is defined for this study as the discharge measured at the Marblemount gage required to create the flow that first puts the pothole in physical contact with surface flow in the main channel of the river. A pothole dry flow is the discharge measured at the Marblemount gage that allows a pothole to become dry or completely devoid of water.

(b) Approach

Connection Flow Determination. A "connected pothole" is defined as a pothole that is physically connected to the main channel of the river by surface water. A "disconnected pothole" has no physical contact with the surface water flow of the river. The following describes the technique used to determine the river flow, measured at the Marblemount USGS gage, at which a given pothole becomes connected to the main channel river flow. For purposes of this study the connection or disconnection flow for a given pothole is considered identical. The only difference between the two is that a connection flow is associated with a rising river flow or upramp and a disconnection flow with a descending flow or downramp.

The data types used to determine pothole connection flows originated from time-linked field observations of river flow and pothole connection/-disconnection status. Connection flow estimates used observations made under stable flow conditions, since dynamic flow conditions (significant changes in river stage) would require the development and use of a complex hydraulic model. Stable flow conditions were present in the early morning hours prior to the upramping wave of dynamic flow or well after the upramping wave had passed a pothole location. The changes in river stage were monitored periodically throughout each test day so that stable flow pothole data could be identified for later use. The spring 1985 pothole study collected data primarily from potholes that trapped or stranded fry during the Jones and Stokes, Inc. 1984 study. Since these potholes were responsible for the trapping and stranding of fry, they were considered to be of most importance for hydrologic data collection. Individual pothole observations were made 5 to 15 times per day during the course of the 13 days of formal pothole testing.

To determine the connection flow of a pothole, two types of data were needed. First, the maximum observed Skagit River flow for a pothole when disconnected from main-channel flow and secondly, the minimum observed flow when the pothole remained connected to the main channel (See Figure 2). These two pieces of data bracket the actual connection flow of a given pothole. In theory, the tighter the bracket between these observations, the closer to the true connection flow. The mean of these two values closely approximates the connection flow of a pothole. When these two data types were available for a pothole, they were used as the primary method of determining the connection flow.

A second method of determining a pothole connection flow was from the direct observation of pothole connection under stable flow conditions. When available, these data were used in conjunction with the approach described above.

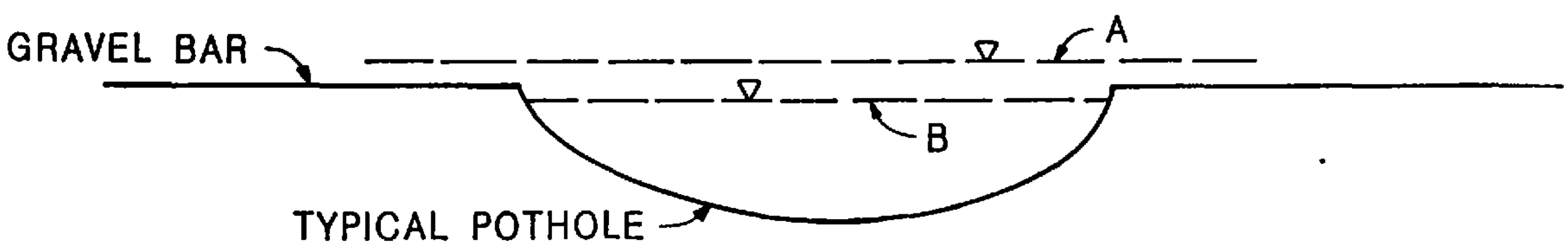
When these data types were not available, two other methods of connection flow estimation were used. The third alternative method used the maximum observed disconnection flow for a pothole. At any river discharge below this level, the pothole will always be disconnected, but it is not known how much higher river flow must go before pothole connection is achieved. Many of the potholes requiring the use of this connection flow estimation alternative were higher flow potholes for which connection flow observations could not be made because they exceeded the highest observed study flows.

The fourth method used connection flow estimates derived from the Jones and Stokes, Inc. 1984 pothole studies. Although the Jones and Stokes, Inc. estimates were derived using the first method described above, their data were collected differently which confounded the connection flows. For example, the maximum disconnected and minimum connected flow observations were not always made under stable flow observations. Secondly, lower river pothole connection flow estimates were tied to predicted Rockport flows rather than known flows at the Marblemount USGS gage. Jones and Stokes, Inc. collected their data in the spring and summer months of 1984 and, due to the dynamic nature of pothole formation and modification brought on by high flows, the change in connection and dry flows is unknown as is the disappearance and formation of potholes between their study and ours. Most of our connection flow estimates used the first two methods described above which are the most accurate means of estimating such a dynamic parameter. The method or source used to calculate each connection flow is specified for each pothole in a summary table that appears in Section IV of this report.

Dry Flow Determination. Once a pothole has become disconnected from main-channel flow, any fry inside are trapped until the pothole becomes reconnected. Once disconnected, if river flow continues to drop, the depth of the pothole will decrease until it goes dry, unless river flow stabilizes. The river flow that coincides with the point at which a pothole goes dry is termed the "dry flow". Our database allows for the estimation of a specific flow at which a pothole typically may go dry. The estimated dry flow for each pothole will, on the average, represent when a particular pothole might go dry. But this estimate can be confounded by many factors such as bank storage, specific pothole drainage, and how long river flow is held down before next upramp. Dry flow estimates, like connection flows, can never be

FIGURE 2

TYPICAL POTHOLE SHOWING WATERLINES USED TO CALCULATE A POTHOLE CONNECTION FLOW



A= Lowest observed endflow where pothole was connected to mainchannel flow.

B= Highest observed endflow where pothole was disconnected from mainchannel flow.

POTHOLE CONNECT FLOW = $(A+B) \div 2$

exact because so many different factors affect them. In any event the values derived are valid predictors of when a particular pothole is expected to go dry; however, these flows must be used carefully due to the dynamic nature of potholes.

The methods used to estimate a pothole's dry flow closely parallel those used to calculate connection flows. The depth of each pothole was monitored daily over the course of the pothole testing period during the spring of 1985. Many of these same potholes were monitored again during the gravel bar stranding studies conducted in August of 1985. Both data sets were then used to produce dry flow estimates for as many potholes as possible.

Three different methods of determining pothole dry flows were used. The first method, and perhaps the most accurate, used the highest observed river flow when the pothole was dry (no water depth) in conjunction with the river flow that created the minimum pothole depth (preferably 0.1 foot). The average of these two values represents an accurate prediction of a pothole's dry flow (See Figure 3).

When data of this type did not exist for a pothole, a regression procedure was used to predict the dry flow of some potholes. The regression required multiple observations of river flow versus pothole depth. Data collected during observation were used to predict a river flow that produces a pothole depth of zero (dry pothole).

The third dry flow estimation procedure used the Jones and Stokes, Inc. dry flow data. We derived these estimates using their data and the first approach discussed above.

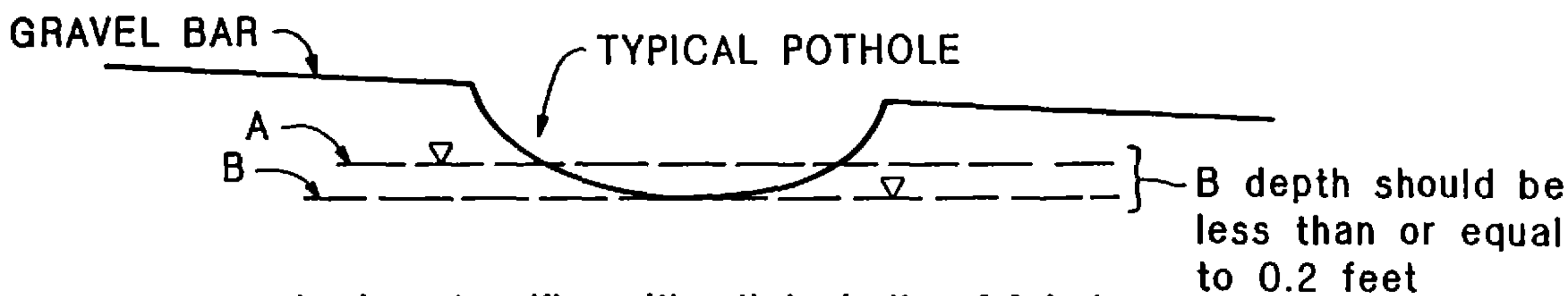
(2) Pothole Trapping and Stranding Significance

(a) Purpose

Another objective of the spring 1985 pothole study was to provide a means for determining the magnitude of salmon fry trapping and stranding in potholes within the Skagit River study area. Earlier research did not provide a means for predicting the relative magnitude of the pothole stranding problem. The impact of pothole dewatering is best measured by the number of fry stranded, not by the number trapped, for a given set of Gorge Powerhouse operations criteria such as ramp rate and beginning and endflow of a downramp event. The number of trapped fry is less significant since they are not normally harmed.
Two possible sources of mortality on trapped fry are predation and elevated water temperatures. Our studies could not confirm either type of mortality during the spring pothole trapping and stranding study. The pothole water temperatures were monitored during the spring study and never exceeded normal levels of water temperatures. Observers constantly monitored their potholes and never witnessed birds preying on live fry trapped in potholes although birds were commonly seen on gravel bars and around potholes. Although these two possible sources of fry mortality may well contribute to total fry mortality it is presumed to be only a small number of fry compared to the total number of fry stranded in potholes. This study was designed so that a matrix could be produced capable of predicting the number of potholes that

FIGURE 3

TYPICAL POTHOLE SHOWING WATERLINES USED TO CALCULATE A POTHOLE DRYFLOW



A= Lowest endflow with pothole depth < 0.2 feet.

B= Highest endflow with a dry pothole.

POTHOLE DRYFLOW = (A+B)÷2

EXAMPLE CALCULATION

Example: Pothole #10 has a minimum depth observation of 0.1 foot on March 10, which corresponds with an endflow of 3650 cfs at Marblemount USGS gage. This pothole also had seven (7) observations where pothole was dry. The third dry observation has the highest endflow of 3550 cfs at the Marblemount USGS gage, so the estimated dryflow would be:

(lowest endflow w/pothole depth ≤0.2 feet + highest endflow w/a dry pothole)÷2 = Dryflow

Pothole #10 Dryflow = (3650+3550)÷2 = 3600 cfs become disconnected and the average number fry trapped and stranded for six combinations of amplitude fluctuations and ramping rates.

(b) Approach

Two information types were needed to construct this matrix: pothole connection flows and the average number of fry trapped and stranded in each pothole. The first step in constructing the matrix was to determine which potholes were affected (connected and disconnected) by the 21 combinations of downramp event beginning and endflows. Once the potholes were identified for each combination, the average-trapped and stranded fry for each pothole were summed, which represents the total trapped and stranded for each combination. Thus, for a downramp with a specified beginning and endflow, the total number of potholes affected could be identified and the summation of the average trapped and stranded could be calculated. The matrix is capable of making trapping and stranding predictions over the range of flows observed during the pothole trapping and stranding study. Beyond this range of flows, data are not available regarding the number of fry trapped and stranded. The accuracy of this estimate is controlled by the limits of the study. For example, observer error and predation on trapped and stranded fry have not been factored into the estimation. If these two variables were factored in the estimates of fry trapped and stranded totals would presumably be higher than those presented. However, the estimate does assume, for the entire vulnerability period, that the largest observed number of fry would be trapped and stranded each day. The highest observed trapping and stranding totals are represented by the largest downramp amplitude tested (6,000 to 3,000 cfs). In reality Seattle City Light has never operated their facilities with such consistently high downramp amplitudes. During the summer (1985) gravel bar stranding study, hydrologic data pertaining to pothole connection and drying flows were collected to supplement data collected the previous spring. These data were collected primarily to determine the connection and dry flows for potholes that connect or go dry below the lowest observed spring flows.

The estimate derived from this approach is used to represent the significance or magnitude of pothole trapping and stranding. This estimate was developed within the limits of the study and does not reflect sources of error such as observer error and predation on fry trapped or stranded in potholes.

(3) Pothole Residency Timing for Salmon and Steelhead Fry

(a) Purpose

Pothole residency timing of salmon and steelhead fry in 28 potholes along the Skagit River was studied by Troutt and Pauley (1985) during the spring and summer of 1985. This study was performed in conjunction with pothole trapping and stranding and gravel bar stranding studies being conducted by R. W. Beck and Associates. Trapped fry were defined as being isolated from the main river in disconnected potholes, and had no relation to salmonid mortality. Mortality from stranding only, results when potholes dewater and go dry. The results of their study are summarized below. For greater detail, refer to the report in Appendix E.

Troutt and Pauley's (1985) study was the first study on the Skagit River specifically designed to evaluate the residency time of salmonid fry in potholes. Their study addressed the following questions:

- Which species of fry are most likely to be trapped in potholes during different seasons of the year?
- How long do salmonid fry remain in individual potholes before moving out?
- How do certain pothole characteristics such as depth, cover, and proximity to the river affect pothole residency time of salmonid fry?

(b) Approach

Troutt and Pauley (1985) selected a subset of 28 potholes representative of the approximately 250 potholes along the Skagit River between Rockport and Newhalem previously identified by Jones and Stokes, Inc. (1984). Potholes were separated into groups based on available cover and proximity to the river because these factors were expected to test for influence on the residence time of young salmonids. Available cover was classified as low, moderate, or heavy based on a subjective evaluation of pothole depth, substrate composition, overhead cover, and undercut banks. Pothole location with respect to the river was designated as "connected" if the pothole was adjacent to the main river and regularly inundated during river flow fluctuations. "Isolated" potholes were relatively far from the main river, on side channels or back sloughs.

Two separate conditions were examined. In the spring research focused on evaluating how river flow fluctuations resulting from Seattle City Light's Skagit River Project affected pothole residency timing of chinook salmon in potholes. A similar study in late summer evaluated pothole residency timing of steelhead and coho salmon in potholes.

Seattle City Light fluctuated river levels on a daily, predetermined test schedule during both studies as required by the R. W. Beck study design. Flow releases at Gorge Dam varied from a high of 4,500 cfs to a low of 2,300 cfs in the spring and 1,700 cfs in the summer. River flows were raised to a predetermined maximum during the night prior to each test and then reduced to their lowest point just before daylight. Decreases in flow were sufficient to separate potholes from the main river. Fish were sampled from potholes during the early morning before flow increase submerged the potholes.

Each test day, fry were removed from each pothole, marked, measured, then returned to the same pothole. On sequential days, the number of marked to unmarked fry was used to estimate the residence time of fry in potholes.

(4) Sauk River Salmon Fry Trapping and Stranding in Potholes

(a) Purpose

Most rivers, whether flows are controlled by man or uncontrolled, have potholes associated with them. Researchers studying potholes and gravel bars on the Skagit, Cowlitz, and the Sultan Rivers have not documented pothole trapping and stranding on an uncontrolled river to compare with a controlled river that has trapping and stranding of salmon fry. The purpose of this study task was to first document the presence and location of potholes on an uncontrolled river, the Sauk River, and secondly to qualitatively determine the magnitude of fry trapping and stranding that might normally take place on a river system of this type.

(b) Approach

The timing of a pothole trapping and stranding survey was agreed to be coincident with a declining river stage following a high-water event. This timing was chosen to give fry an opportunity to become trapped in potholes, but before they became preyed upon or stranded. The Sauk River was chosen because of its close proximity to the Skagit drainage and because the Skagit and Sauk River gravel bars and potholes were similar in geology and conformation. Aerial maps of the Sauk River were used to identify and locate gravel bars to be searched for potholes and trapped and stranded fry. The Sauk River from the Darrington Bridge to the second Government Bridge was surveyed in two days using drift-boats for transportation to each gravel bar. The 15-mile survey was split into two reaches. The upper reach of the survey, Darrington (River Mile 22.0) to the mouth of the Suiattle River (River Mile 13.0), is approximately 9 miles long. The lower reach began at the Suiattle River and extended downstream to the Second Government Bridge (River Mile 6.8) for a reach length of 6.2 miles.

Each gravel bar was surveyed for potholes and each pothole was numbered and total trapped and stranded fry were visually counted. A small number of potholes were electroshocked to determine the general composition of trapped fry.

2. 1985 SUMMER/FALL GRAVEL BAR STRANDING FIELD STUDY

a. Objectives and General Description of Field Studies

The following list describes the six objectives of this study which were developed and agreed upon by Seattle City Light, members of the Skagit Standing Committee, and R. W. Beck and Associates. It should be mentioned that this work represents a shift in original project scope of services from pothole studies to gravel bar stranding studies.

(1) Identify measurable factors affecting gravel bar stranding of steelhead and coho fry between Rockport and Newhalem on the Upper Skagit River.

(2) Examine the relationship of such factors to each other and to

gravel bar stranding for the purpose of devising strategies to minimize losses.

(3) Determine the "window" of steelhead and coho vulnerability to gravel bar stranding in terms of flow, calendar date, and fry size or age.

(4) Assess the extent of gravel bar stranding by steelhead and coho fry within the project area.

(5) Determine residence time of steelhead and coho fry moving into and out of potholes.

A study design was developed that was consistent with the data requirements of the objectives and would be operationally possible for Seattle City Light. Once this design was approved by the Skagit Standing Committee, it was implemented. Unlike the spring pothole stranding tests conducted on weekend days, these tests were completed on consecutive days. The reason for this approach was to conduct the tests while fry densities were relatively stable. To meet this prerequisite, it was necessary to begin near the peak of fry emergence and complete them before fry abundance changed significantly. The peak was identified by monitoring a pre-determined set of potholes and gravel bars twice/week until fry emergence levels became high enough to initiate the formal gravel bar stranding testing phase. The testing phase required the completion of 18 one-day tests which were conducted between August 2-20, 1985. The testing parameters were: two levels of downramp amplitude fluctuations (2,000 and 4,000 cfs); and three levels of downramping rate (1,000, 5,000 cfs/hour, and an accelerated ramping rate) that were controlled by Seattle City Light for the tests. All of these parameters were measured at Newhalem. A total of 35 gravel bar sites were chosen for study (see Figure 1). These sites were balanced with respect to site location (middle or lower reach), bar slope (three levels), and bar substrate type (two levels). Three replicates of each gravel bar type were selected based on a complete inventory of gravel bars within the study area. Table 3 displays the test types by date for the summer/fall gravel bar stranding studies. Appendix F contains a summary of the field data collected during the gravel bar stranding tests.

Four secondary investigations were conducted in conjunction with the gravel bar stranding tests. The first, an observer accuracy experiment was conducted to test the sampling accuracy of the visual observation technique used to locate stranded fry on gravel bars. Each test required random placement of fry on predetermined gravel bar test sites without the observer's knowledge prior to the test. The number and exact locations of the marked fry were documented so that recoveries could be interpreted accurately.

Individual bar characteristics (e.g., large rocks, roots, debris, bar depressions, and logs) were mapped during the course of the study for each 200 foot gravel bar test site. This mapping procedure allowed fry stranding locations to be compared with the physical features of a gravel bar.

TABLE 3
TEST TYPES BY DATE
SUMMER 1985 GRAVEL BAR STEELHEAD STRANDING STUDY

DATE	TEST NO.	EVENT DESCRIPTION AMP	RAMP	Double Test AMP	Double Test RAMP
AUGUST 2, 1985	1	A1	R2	A1	R2
AUGUST 3	2	A1	R2		
AUGUST 4	3	A2	R3		
AUGUST 5	4	A2	R1		
AUGUST 6	5	A2	R2		
AUGUST 7	6	A1	R3		
AUGUST 9	7	A2	R2		
AUGUST 10	8	A2	R3		
AUGUST 11	9	A1	R2	A1	R2
AUGUST 12	10	A1	R3	A1	R3
AUGUST 13	11	A1	R1		
AUGUST 14	12	A2	R1		
AUGUST 15	13	A2	R1		
AUGUST 16	14	A1	R1	A1	R3
AUGUST 17	15	A1	R3		
AUGUST 18	16	A2	R3		
AUGUST 19	17	A2	R2		
AUGUST 20	18	A1	R2		

Amplitude: A1 = 2000 cfs
A2 = 4000 cfs

Ramp Rate: R1 = 500 cfs/hr for 1/2 hour then 5000 cfs/hr (1).
R2 = 1000 cfs/hr
R3 = 5000 cfs/hr

(1). The accelerated ramprate for the A2 = 4000 cfs tests had an actual downramp of 500 cfs/hr for 1.5 hours rather than 0.5 hours.

Four of the 18 gravel bar tests included daylight downramping in conjunction with the darkness downramping to determine if there are any detectable differences between light and dark downramping on steelhead and coho gravel bar stranding.

Electroshocking was done throughout the gravel bar testing phase in three different habitat types; main-channel gravel bar, back-slough, and potholes. This information was used to compare the species composition and the length frequencies of the populations occupying these habitats with the "population" of fry that are stranded on gravel bars.

(1) Study Design

The experimental design used for the gravel bar stranding study in 1985 was based on study objectives developed through discussions with Seattle City Light staff and the Skagit Standing Committee. Background information was obtained in part from a review of previous summer gravel bar stranding studies. The factors incorporated in the study design consisted of those that were of particular interest and those that were judged likely to affect stranding significantly.

In statistical terminology a gravel bar stranding experiment involves the application of various treatments (flow fluctuations) to a number of subjects (gravel bar plots). A unit plot was defined as a 200-foot section (as measured parallel to the river) of gravel bar which is relatively uniform with respect to substrate size and slope.

During preliminary site surveys numerous potential unit plots or sites were identified and cataloged. Study sites were then systematically selected on the basis of their location above or below the Cascade River at Marblemount, bar slope, and substrate size. The classification of the 35 sites selected is shown in Table 4. For practical reasons the site selection within each stratum was not always random. For example, safe access by field samplers eliminated certain sites from consideration. It is doubtful that serious biases were created through the selection process; however, some caution is advisable in interpreting results extrapolated beyond the study sites.

The primary treatment factors were downramp amplitude and rate. Two levels of amplitude were tested (2,000 and 4,000 cfs of flow reduction respectively) and three levels of ramp rate. The latter levels consisted of 1,000 cfs/hour, 5,000 cfs/hour and an accelerated rate which started at 500 cfs/hour and then increased to 5,000 cfs/hour. The experiment was balanced with respect to these factors with each treatment combination repeated three times over 18 test dates (Table 5).

In addition to the primary treatment factors, the effect of day versus night downramping was of interest. The 18 tests referred to above were conducted during darkness. Four daytime tests of 2,000-cfs amplitude were conducted three hours following the completion of each of four 2,000 cfs night tests.

TABLE 4

SUMMARY TABLE SHOWING THE STUDY DESIGN GRAVEL BAR TYPES AND REPLICATES FOR THE SUMMER/FALL 1985 GRAVEL BAR STRANDING STUDY

RIVER LOCATION	SLOPE CATEGORY	SUBSTRATE CATEGORY	NUMBER OF GRAVEL BAR SITES
MIDDLE REACH	0-5%	<3"	2
		>3"	2
	>5-10%	<3"	4
		>3"	5
	>10%	<3"	3
		>3"	2
LOWER REACH	0-5%	<3"	4
		>3"	4
	>5-10%	<3"	2
		>3"	2
	>10%	<3"	4
		>3"	1
	TOTAL NUMBER OF BAR SITES		35

TABLE 5
SUMMARY TABLE SHOWING THE STUDY DESIGN EVENT TYPES
OVER THE TEST PERIOD FOR SUMMER/FALL 1985
STEELHEAD GRAVEL BAR STRANDING STUDY

DOWNRAMP AMPLITUDE FLUCTUATION (CFS)	EVENT CATEGORY	RAMPING RATE (CFS/HOUR)	REPLICATE NUMBER (TESTS)	TOTAL NUMBER OF TESTS
4000 CFS	UPPER 2000 CFS DEWATERED	ACCELERATED	3	9
		1000	3	
		5000	3	
	LOWER 2000 CFS DEWATERED	ACCELERATED	3	
		1000	3	
		5000	3	
2000 CFS	D A Y	ACCELERATED	3	4
		1000	3	
		5000	3	
	N I G H T	ACCELERATED	3	9
		1000	2	
		5000	2	

To shed further light on stranding behavior, the coordinates of each fry observed and each pre- and post-downramp waterline were recorded. This allowed the splitting of each 4,000-cfs amplitude test into two successive 2,000-cfs tests.

The experimental design called for controlling endflow effects by requiring each downramping test to end at 2,500 cfs. Fry emergence and density change over time and are controlled by many factors such as adult escapement and water temperature during the incubation period. The gravel bar stranding tests were conducted on consecutive days during or near the peak of fry emergence so that fry density changes would be minimized as much as possible. During the spring 1985 pothole study, it was apparent that fry densities change unpredictably in each of the pothole areas studied. These observations combined with the unsuccessful attempts by past researchers to accurately monitor fry density led to the approach taken. Systematic trends in population size due to seasonal changes were avoided by balancing replications over time.

(2) Reconnaissance of Gravel Bar Sites

The reconnaissance involved a complete inventory of all gravel bars between Copper Creek and Rockport and the selection of 35 gravel bar sites (all 200 feet long). The study design called for three replicates of each of the six possible combinations of gravel bar slope and substrate for each of the two study reaches for a total of 36 gravel bar sites. The reconnaissance surveys were unable to locate all of the possible combinations, so only 35 sites were used. The most difficult combination to find was steep slope (greater than 10%) with small substrate (less than 3 inches). It should also be noted that the upper reach (Copper Creek to Gorge Powerhouse) was not studied due to several overriding operational and logistical factors. No fry stranding data were collected from the upper reach but the gravel bars were characterized by slope, substrate, and length during a survey completed near the end of the spring 1986 gravel bar stranding study. The 35 sites chosen met the requirements of the study design, which specified several levels of testing variables such as upriver vs. down-river bar location, high/moderate/low gravel bar slopes, and large vs. small bar substrate. Once the reconnaissance survey was completed, the gravel bar types and locations were selected so that they met the requirements of the study design and were logistically possible to sample. After the 35 gravel bar sites had been selected, each was prepared for use by setting up reference point rebar markers with a coding system (Figure 4). Where possible, gravel bar areas used during past gravel bar stranding studies were selected so that past gravel bar stranding histories could be compared with the results of this study. The reconnaissance also involved selecting a second set of index potholes that were to be monitored in conjunction with gravel bars.

(3) Gravel Bar Stranding Tests

Three data sets were collected by an observer that was responsible for a gravel bar location which had 2-4 gravel bar study sites. The high and low waterlines were measured from predetermined reference points, stranded fry were counted, their precise location measured as shown in Figure 5, and the

FIGURE 4

TYPICAL GRAVEL BAR STUDY SITES PLAN

SCALE : 1" = 100'-0"

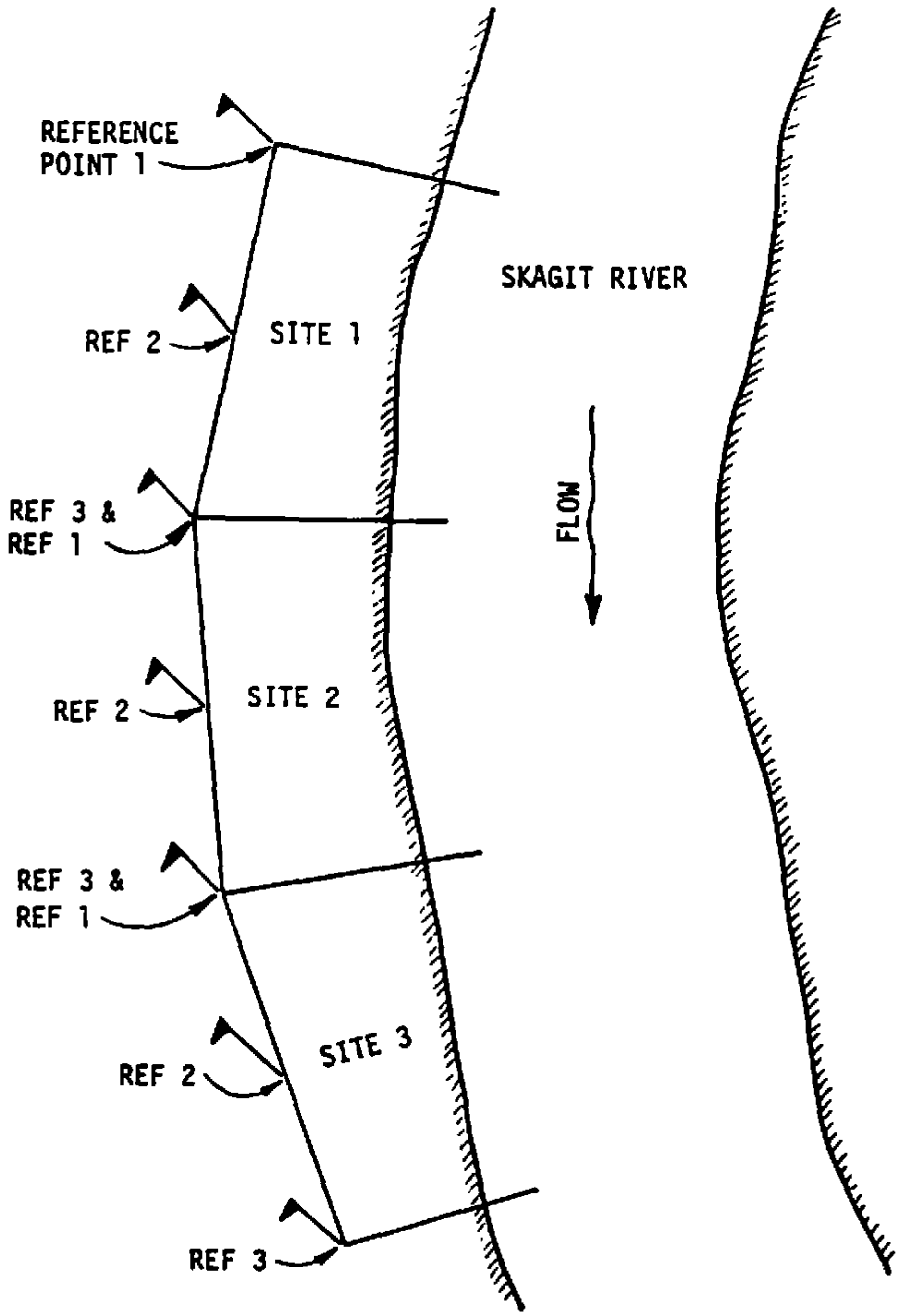
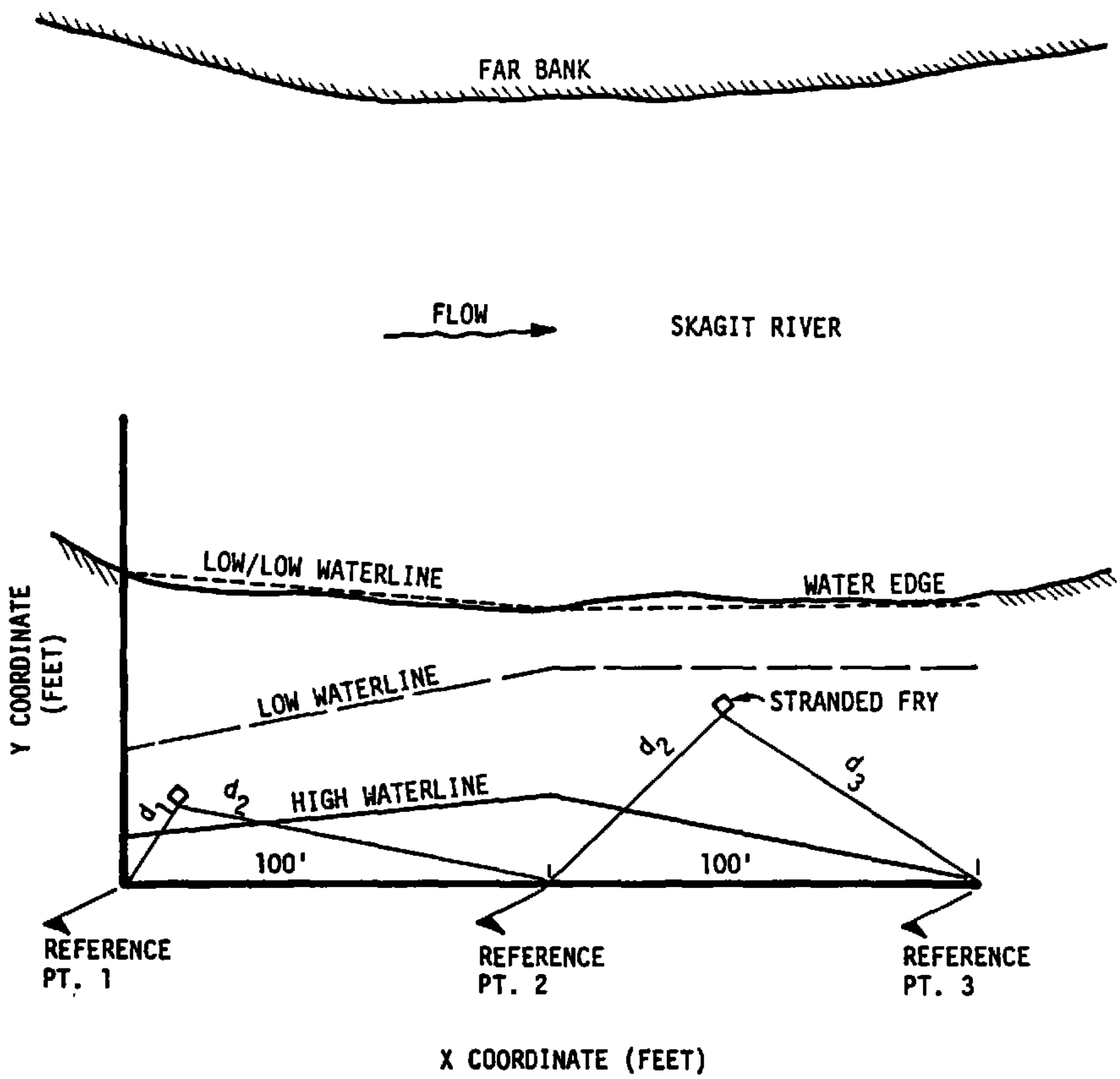


FIGURE 5

PLAN OF 200' GRAVEL BAR STRANDING SITE WITH TYPICAL WATERLINE AND STRANDED FRY COORDINATES

SCALE :1" = 40'-0"



NOTES:

1. LOW/LOW WATERLINE PRESENT IN DOUBLE EVENT TEST DAYS DURING SUMMER 1985 STUDY PHASE ONLY.
2. d_1, d_2 AND d_3 DENOTE FRY STRANDING MEASUREMENTS.

species and total length of each stranded fry was recorded for each site. The data collection procedures and the data forms used are provided in Appendix C.

Each waterline shown in Figure 5, whether a high, low, or low/low waterline, was represented by measurements from the reference points at each gravel bar site. Between the reference points the actual waterline is typically non-linear as represented by the waters-edge line in Figure 5 which roughly follows the measured low/low waterline.

Pothole data were also collected during the gravel bar stranding testing period. These data were collected to supplement pothole hydrologic data collected during the 1985 Spring Pothole Trapping and Stranding Study so that pothole connection and dry flows could be more accurately estimated. In addition to the hydrologic data, observers collected data on the number of trapped and stranded fry. These data were not intended to be used in an analysis as it was qualitative in nature, but as a means of monitoring the relative extent of pothole trapping and stranding during summer months when both steelhead and coho fry are present. The data form and procedure manual for this data collection effort are shown in Appendix C.

(4) <u>Data Processing and Analysis</u>

The data from the field forms were entered onto microcomputer using the R-Base 5000 software program. Detailed data processing algorithms are available upon request. All analysis and data processing was done on micro computers (IBM PC compatible). While the use of micros imposed some constraints on the complexity of statistical analyses, the flexibility and portability more than compensated for this weakness. All data currently reside on R-BASE 5000 files. The statistical analyses were performed using a software package called CRISP (marketed by CRUNCH SOFTWARE).

The statistical analysis was performed as follows. Examination of cell means versus standard deviation suggested a linear relationship implying that a log transformation might be suitable to stabilize the variance. Inspection of cell variances for transformed data verified the appropriateness of this transformation.

Table 6 shows the independent variables used in the analysis of night tests (day versus night stranding is analyzed elsewhere in this report) and the number of levels at which each was observed.

TABLE 6

LEVELS OF EACH INDEPENDENT DESIGN VARIABLE
1985 SUMMER/FALL STEELHEAD FRY GRAVEL BAR
STRANDING STUDY

Variable	Number of Levels
Amplitude	2
Ramp Rate	3
Slope	2(1)
Substrate	2
River Location	2
Week Number ..	3
Total Number of Cells ..	144

(1) - Slope levels 2 and 3 were pooled.

Preliminary review of data showed a marked difference in stranding between the sites above and those below Marblemount. Separate ANOVA were thus performed in RIVLOC=1 (above Marblemount) and RIVLOC=2 (below Marblemount).

b. Subtask Purposes and Approaches

(1) Biological Factors Affecting Fry Vulnerability to Gravel Bar Stranding

(a) Purpose

During the summer months (July-October), there are primarily two species of salmonid fry, steelhead and coho, that are present in the Skagit River that could be affected by gravel bar stranding. Vulnerability to gravel bar stranding of steelhead and coho fry begins as soon as emergence from gravel takes place and probably continues until both species leave the Skagit as smolts. The peak vulnerability period, which occurs when the majority of gravel bar stranding takes place, may only affect a fry species during a particular size or time related period. The major purposes of this study effort were to understand and document the biological window of vulnerability of steelhead and coho fry to gravel bar stranding.

(b) Major Objectives

- Determine which species are vulnerable to gravel bar stranding.
- Determine the biological window of vulnerability as a function of fry size and/or calendar date.
- Determine when most fry have exceeded the size/age of peak vulnerability.

(c) Approach

Two types of data were collected to provide information needed to meet the needs of the objectives discussed above. First, the species and the total length of each fry found stranded on gravel bars were recorded by date and location on gravel bar. Second, fry were electroshocked from several different habitat types (main channel, back-slough, and potholes). Species and total length data were collected for each fry captured. Electroshocking was conducted periodically throughout the August 1985 gravel bar test phase. The analysis of these data involved a time-wise comparison of the species composition and length frequency distributions of fry stranded on gravel bars versus representative samples of electroshocked fry from main-channel habitat, which is the habitat dewatered during a downramping event and occupied by fry vulnerable to gravel bar stranding. If a particular fry age/length interval is more susceptible to gravel bar stranding than the other, there will be clear differences between the length frequency distributions of each population subsample. Similarly, differences in the species composition of fry stranded on gravel bars and inhabiting main-channel habitat will provide a measure of species specific vulnerability. For a fry species to be vulnerable to gravel bar stranding, it must be present in vulnerable habitat. For this reason, three different habitat types were sampled for fry presence to determine habitat preferences and presence of fry species in them. A fry species exhibiting a habitat preference for the area dewatered by downramping would be more vulnerable than a species occupying another type of habitat that is less affected by downramping.

To determine the boundaries of the peak vulnerability period, the beginning and the end must be defined. Fry are not susceptible to gravel bar stranding until they emerge from the gravel. Once they have emerged and, provided they remain in habitat dewatered by downramping, they will remain vulnerable until they grow large enough to avoid gravel bar stranding or they move out of the gravel bar stranding habitat. Data used to define the boundaries of peak vulnerability included electroshocking data to monitor growth from emergence until it appeared that gravel bar stranding rates had declined dramatically. Electroshocking took place throughout the entire experimental sampling phase from August 1 to October 5, 1985. Electroshocking took place throughout the entire experimental sampling phase from August 1 to October 5, 1985. These data can be coupled with stranded fry length data over the same time period to determine the peak vulnerability period. In addition, three gravel bar areas were monitored bi-weekly for stranded fry from August 31 to October 5, 1985 following twenty daily gravel bar stranding tests from August 1 to August 20. The three bars chosen for the late season gravel bar monitoring were Rockport, Marblemount, and Fungus bars. These bars represented the middle and lower river bars that stranded large numbers of fry relative to the nine bars not chosen. The monitoring program was continued until stranded fry numbers were reduced to zero. When this occurred, it was assumed to represent the end of the peak vulnerability.

(2) Fry Stranding Location Relationships

(a) Purpose

The precise location of a stranded fry could be influenced by a variety of hydrologic, physical and temporal factors such as ramp rate, amplitude fluctuation, time of day, or physical features on the bar. Relating the stranding locations to these factors could provide further insight into the understanding of gravel bar stranding phenomena. The purpose of this task was to explore gravel bar stranding location with respect to these factors.

(b) Approach

The basic approach involved constructing a graphic plot of a gravel bar study site with the precise locations of each stranded fry, gravel bar features, and downramp beginning and ending waterlines with respect to the reference points established at each 200-foot gravel bar site. The first requirement of this task was to develop a means of accurately identifying the location of fry within each of the 35 gravel bar study sites. This was accomplished by taking triangulation coordinates from two reference points for each stranded fry (See Figure 5). These coordinates were then transformed and placed on a graphical plot representing each bar site. The same technique was used to map out the coordinate locations of physical features present on the individual gravel bars. For example, the location of a pothole was set by taking the coordinate measurements for the pothole. The final coordinates used to construct the gravel bar plots relate to the high and low waterlines (See Figure 5).

(3) Significance of Steelhead/Coho Fry Gravel Bar Stranding

(a) Purpose

Gravel bar stranding of salmonid fry has been documented by many fisheries researchers over the years. Most of these studies had no quantitative means for determining the magnitude of gravel bar fry stranding impacts on the Skagit River. The intent of this study task was to develop a method of estimating the number of fry stranded on gravel bars between Newhalem and Rockport, given certain hydraulic conditions relating to the amplitude fluctuation of a downramp event, the downramp rate, and the river discharge level at the end of the downramp. The matrix that was developed for this purpose can be used to evaluate the magnitude and impact of gravel bar stranding on salmon fry in the spring and steelhead in the summer/fall. The matrix was developed and is subject to the limitations of the study. It does not and could not adjust for several potential sources of error such as observer error and predation on stranded fry.

(b) Approach and Assumptions

Two types of data were needed to develop the matrix. First, a comprehensive inventory of all gravel bars within the 26 mile study area had to be completed. Each gravel bar was characterized by "bar slope", or steepness and primary or dominant substrate size. The length of each bar type was summed for each study reach. The study reach breakdown follows: the upper river reach begins at Newhalem and extends downstream to Copper Creek; the middle river reach begins at Copper Creek and ends at the mouth of the Cascade River; and the lower river reach extends from the Cascade River downstream to the mouth of the Sauk River (See Figure 1).

The second data type used to complete the matrix was an estimate of the average number of fry stranded on a 200-foot bar (the standard length of this study's gravel bar test sites) for all 108 combinations of river reach, bar slope, substrate type, downramp amplitude fluctuation, and ramp rate. These averages were derived from the gravel bar stranding tests that are described in greater detail in Section III of this report. Using these two data types in conjunction provides a means for predicting the total fry stranded for six different flow scenarios. The only exception to this methodology is that the values to estimate the average number of fry stranded in the upper river reach were the same as those used for the middle reach since the upper reach was not studied. The following rationale was used in reaching this decision. Gravel bar stranding rates were higher in the middle river than in lower river. This was reason enough to assume that upper river stranding rates would be equal to or higher than the corresponding stranding rates for the middle river. The effect of Gorge Powerhouse's flow fluctuation dissipates with distance from the source of the fluctuation. If the lower river had lower stranding rates on the average than the middle river then it would seem reasonable to predict that the upper river would have even higher stranding rates than the middle river since it is so much closer to the source of flow fluctuations. However, many other factors enter into this rationale such as fry density differences between reaches and whether the middle river and upper river are both close enough to Newhalem that the effect would be indiscernible. After taking all of these factors into consideration, the decision was reached to use the middle river stranding values for the upper river rather than make some broad and far reaching extrapolations.

The results of the matrix could be applied to the daily flows of the Skagit River during the period of peak fry vulnerability to determine the overall impact of gravel bar stranding on an annual basis. The approach used involves taking the highest predicted stranding total from the matrix and multiplying this value by the number of days fry are vulnerable to gravel bar stranding. Within the limits of the study this approach represents a "high-side" prediction of total fry stranded during the fry vulnerability period.

(4) Observer Accuracy Testing

(a) Purpose

Gravel bar fry stranding tests have been conducted on the Skagit, Cowlitz, and Sultan Rivers in recent years. All of these studies required visual counts of fry stranded. The purpose of this experiment was to determine the accuracy of a typical observer attempting to locate fry visibly stranded on a gravel bar of several different physical makeups. A determination of observer accuracy is extremely important to a quantitative study of this type. Observer accuracy was determined by comparing the number of fry placed on a gravel bar in a visible position to the number of fry actually detected by an observer.

(b) Approach

The original approach involved random placement of a known number of live fry on one of the 35 bar sites used in this study. The observer then searched the entire bar for stranded fry, both the fry placed on the bar for the control test and those naturally stranded. This technique failed because live fry, when deposited on the bar with a bucket full of water showed a definite state of panic resulting in an immediate search for cover under rocks or debris. Once concealed, these fry did not always become visible to the observer. All of the fry struggled once the water drained from the immediate area. Some of these fry worked their way out from underneath cover and others did not. A primary assumption of these tests was that all fry deposited on the gravel bar remain visible so that the observer has a chance to find them. Fry that are stranded beneath cover could not be found by the observer which violates an essential principle of the experiment.

Our second approach involved placing dead fry, stranded from the previous day, on a predetermined bar site and measuring the precise locations of each fry on the site. The number of fry placed on a bar was varied so that the observer had no preconceived idea regarding the number of fry he or she would be searching for on a given 200-foot-long gravel bar site. Control tests were also conducted on different types of gravel bars to see if the complexity of the substrate affected observer accuracy.

3. 1986 SPRING GRAVEL BAR STRANDING FIELD STUDY

a. Objectives and General Description of Field Studies

The spring 1986 gravel bar stranding studies were requested by Seattle City Light and agreed upon by the Skagit Standing Committee and R. W. Beck and Associates. The need for this additional work resulted in part from a reanalysis of historical gravel bar stranding data for Skagit River salmon fry. The reconstruction and reanalysis of the data revealed that multivariate analyses could not be conducted due to data and sampling constraints and variability inherent in a series of studies that were not truly intended to be analyzed in combination. The data had several other weaknesses that prevented a reanalysis from determining anything conclusive. This reanalysis did provide a clear picture of how a study could be designed.

The objectives of these studies are identical to those of the summer/fall 1985 gravel bar stranding studies discussed in Section V. The study approach and design used the gravel bar stranding model developed for the summer/fall steelhead stranding study as a basis of the study design developed for the spring studies. The only changes involved new levels of amplitude, ramping rate, and endflow levels. Amplitude fluctuations had two levels (2,000 and 4,000 cfs), downramp rates two levels (1,000 and 5,000 cfs/hour), and endflow levels of 3,000 and 3,500 cfs as measured at Marblemount. Another notable study requirement involved the beginning flows used for each test. To achieve the two required endflows at Marblemount, the beginning flows had to be manipulated at the Gorge Powerhouse. The study was designed to allow Seattle City Light to exceed the prescribed beginning flows if the flow was held stable for one hour prior to the start of the desired downramp. The hydrographs in Appendix A show that beginning flows were exceeded on only a few occasions. Table 7 displays the test types, by date, for the spring 1986 salmon fry stranding tests. A total of 24 tests were conducted between March 13 and April 14, 1986.

Three small-scale experiments were completed during this study phase, all of which were designed to contribute to a better understanding of pothole trapping and stranding and gravel bar stranding mechanism. For years fry stranding studies emphasized the possible effects of scavenged fry by predators such as birds and raccoons on the observed number of fry seen on gravel bars by observers. A small experiment was conducted to determine the level of these effects on data collected by observers. Another smaller study conducted at the time of the gravel bar stranding tests consisted of a series of experiments aimed at determining the "rate of fry recruitment" to potholes of different types and locations. One of the primary purposes of this study was to determine how quickly fry reinhabit potholes that have gone dry, stranding the fry within them.

The purpose of the third experiment was to determine the accuracy of a typical observer attempting to locate fry stranded on a gravel bar of several different physical makeups. A determination of observer accuracy is extremely important to a quantitative study of this type. Observer accuracy was determined by comparing the number of fry placed on a gravel bar in a visible position to the number of fry actually detected by an observer.

(1) <u>Study Design</u>

The experimental design was similar to that used for the 1985 study. The study sites used in 1985 were resurveyed, remarked, and used again with only minor modifications. Table 8 shows their classification with respect to location, substrate and slope.

The flow schedule was modified to accommodate two amplitude levels, two ramp rate levels, two endflow levels, and three temporal replicates of each treatment combination resulting in the 24-day test scheme displayed in Table 9.

(2) <u>Reconnaissance of Gravel Bars</u>

The reconnaissance of gravel bars had two different phases. The general approach to gravel bar site selection focused on using the same sites identified in the earlier study as they fit the study design requirements. Consequently, the gravel bars used in the 1985 Summer/Fall Gravel Bar Stranding Study were resurveyed to document any changes in substrate type or gravel bar slope. If they remained unchanged they were selected and, if they had changed, they were replaced by another site. The study design required a balanced distribution of gravel bar sites with respect to middle/lower river, gravel bar slope, and substrate type. A second survey was conducted to locate gravel bar sites that could replace those that no longer fit the design requirements.

Both the Summer/Fall 1985 and the Spring 1986 Gravel Bar Stranding

TABLE 7
TEST TYPES BY DATE
SPRING 1986 GRAVEL BAR SALMON STRANDING STUDY

DATE	TEST NO.	-----EVENT DESCRIPTION----- AMP (1)	RAMP (1)	END FLOW (2)
MARCH 13, 1986	1	A2	R1	E1
MARCH 14	2	A1	R1	E1
MARCH 15	3	A2	R1	E2
MARCH 16	4	A2	R2	E2
MARCH 17	5	A2	R2	E1
MARCH 18	6	A1	R2	E1
MARCH 19	7	A1	R1	E2
MARCH 20	8	A1	R2	E2
MARCH 26	9	A2	R1	E2
MARCH 27	10	A1	R2	E2
APRIL 1	11	A1	R1	E1
APRIL 2	12	A1	R1	E2
APRIL 3	13	A2	R2	E1
APRIL 4	14	A2	R1	E1
APRIL 5	15	A2	R2	E2
APRIL 6	16	A1	R2	E1
APRIL 7	17	A1	R2	E2
APRIL 8	18	A1	R1	E2
APRIL 9	19	A2	R2	E1
APRIL 10	20	A1	R1	E1
APRIL 11	21	A2	R1	E1
APRIL 12	22	A2	R1	E2
APRIL 13	23	A1	R2	E1
APRIL 14	24	A2	R2	E2

Amplitude: A1 = 2000 cfs
A2 = 4000 cfs

Ramp Rate: R1 = 1000 cfs/hr
R2 = 5000 cfs/hr

End Flow: E1 = 3000 cfs
E2 = 3500 cfs

(1) Measured at the Newhalem USGS Gage.

(2) Measured at the Marblemount USGS Gage.

TABLE 8

SUMMARY TABLE SHOWING THE STUDY DESIGN GRAVEL BAR TYPES AND REPLICATES FOR THE SPRING 1986 GRAVEL BAR STRANDING STUDY

RIVER LOCATION	SLOPE CATEGORY	SUBSTRATE CATEGORY	NUMBER OF GRAVEL BAR SITES (REPLICATES)
MIDDLE REACH	0-5%	<3"	2
		>3"	2
	>5-10%	<3"	4
		>3"	5
	>10%	<3"	3
		>3"	2
LOWER REACH	0-5%	<3"	4
		>3"	4
	>5-10%	<3"	2
		>3"	2
	>10%	<3"	4
		>3"	1
	TOTAL NUMBER OF BAR SITES		35

TABLE 9

SUMMARY TABLE SHOWING THE DESIGN AND EVENT TYPES OVER THE TEST PERIOD FOR THE SPRING 1986 GRAVEL BAR STRANDING STUDY

DOWNRAMP AMPLITUDE FLUCTUATION (CFS)	EVENT CATEGORY	RAMPING RATE (CFS/HOUR)	ENDFLOW (CFS)	TEST NUMBER (1)	WEEK NUMBER	TOTAL NO. OF TESTS
4000 CFS	UPPER 2000 CFS DEWATERED	1000	3000	1 13 21	1 2 3	12
			3500	3 9 22	1 2 3	
		5000	3000	5 15 19	1 2 3	
			3500	4 14 24	1 2 3	
	LOWER 2000 CFS DEWATERED	1000	3000	1 13 21	1 2 3	
			3500	3 9 22	1 2 3	
		5000	3000	5 15 19	1 2 3	
			3500	4 14 24	1 2 3	
2000 CFS	2000 CFS DEWATERED	1000	3000	2 11 20	1 2 3	12
			3500	7 12 18	1 2 3	
		5000	3000	6 16 23	1 2 3	
			3500	8 10 17	1 2 3	

(1). See Table 7 for the test number.

Studies collected data from gravel bar sites between Copper Creek and Rockport. The stream reach above this area was not evaluated due to several constraints imposed by the study design and manpower/logistic considerations. Although not truly part of the initial reconnaissance effort, a final gravel bar survey of the upper river (Newhalem to Copper Creek) was made to complete the inventory of gravel bars within the entire study area. The results of this survey are presented in the results section of this report.

(3) Gravel Bar Stranding Tests

The general approach and methodology used for these tests were almost identical to those used during the 1985 summer/fall gravel bar stranding tests. The only real difference is that the high-water line of a test was not monitored daily by the observer because, unlike the summer/fall tests, the high-water line did not change significantly because endflow water levels of the four different test types were controlled by the study design. The details for data collection procedures and example data forms are found in Appendix C.

(4) Data Processing and Analysis

The same approach and methodology as the one described above for the 1985 study were used in 1986. Note that the statistical procedures used for both analyses consisted of classical analysis of variance and t-tests on log-transformed data. (This transformation successfully stabilized the variance for both data sets). The response variable in all analyses was the number of fry stranded per bar site per event.

b. Subtask Purposes and Approaches

(1) Biological Factors Affecting Fry Vulnerability to Gravel Bar Stranding

(a) Purpose

Gravel bar stranding of salmonid fry is dependent on the fry being present and, when present, occupying gravel bar habitat dewatered by downramp events. There were four salmonid species; chinook, chum, pink, and steelhead present in the Skagit River during the field portion of these studies. Every other year (odd years) pink salmon return to the Skagit River to spawn. Pink salmon that spawned in the fall of 1985 produced emerging fry in the spring of 1986 that were exposed to gravel bar stranding. Following emergence, pink fry move quickly downstream toward saltwater and, as such, are vulnerable to gravel bar stranding for only a short time. Chum salmon fry resulting from fall spawning adults, like pink fry, spend only a short amount of time in the upper Skagit River on their way to saltwater. Chum, unlike pink salmon, spawn every year. Chinook salmon also spawn every year in the fall, and their fry emerge in the spring months and are vulnerable to gravel bar stranding since the fry rear in the Skagit River for some time after emergence (typically 90 days). Steelhead juveniles are also present in the spring months, having over-wintered after emergence in the previous summer/fall (typically between July and August). Given that these species are present as described above, the major objectives of these studies were:

- Determine the relative vulnerability of these four salmonid species to gravel bar stranding.
- Determine the biological window of vulnerability as a function of fry size and/or calendar date for each species.
- Determine when the fry of each species have exceeded the size/age of peak vulnerability.

(b) Approach

The methods used to accomplish these objectives are identical to those described earlier in this section as applied to steelhead and coho fry data collected August-October 1985. The spring 1986 gravel bar stranding tests were conducted between March 13 and April 13. Further sampling after the formal testing phase did not take place as planned.

(2) Fry Stranding Location Relationships

(a) Purpose

Precise stranding locations of fry may be influenced by several factors including downramping rate, amplitude fluctuation of the downramp, ending flow of the downramp, and physical features on each gravel bar. The purpose of this task was to explore gravel bar stranding location with respect to these factors.

(b) Approach

The same graphical plotting approach described earlier in this section was used to explore the possible relationships between fry stranding location and the aforementioned physical and hydrological factors. The results were hampered by extremely low numbers of fry stranded on individual gravel bars. For many of the graphical plots, each representing a 200 foot section of gravel bar, less than three fry were stranded for any particular comparison type (e.g., 4,000 cfs amplitude fluctuation, 1,000 cfs ramping rate and 3,000 cfs endflow). For this reason, the only plots that were usable were those showing the stranding locations of all fry for a particular site regardless of the test type.

The disappearance of gravel bar features between the fall of 1985 and the spring of 1986 was another problem that could not be anticipated prior to the spring studies. The significance of this was that there were relatively few gravel bar sites possessing any distinguishable features. Therefore, any possible relationship between fry stranding locations and physical characteristics of a gravel bar could not be fully examined.

(3) Significance of Gravel Bar Stranding

(a) Purpose

The intent of this study task was to develop a method for estimating the number of fry stranded on gravel bars between Newhalem and Rockport Bar given certain hydraulic conditions relating to the amplitude fluctuation of a downramp event, the downramp rate, and the endflow achieved at the end of a downramp event. The results of the matrix produced can be applied to the daily dam operations to estimate the number of fry stranded on gravel bars through the season. This stranding total can then be used to evaluate the magnitude of the impact on salmonid resources in the Skagit River.

(b) Approach

The approach and methodology used to develop the matrices were identical to those developed and used for the summer/fall steelhead gravel bar stranding study.

(4) Scavenging of Stranded Fry

(a) Purpose

Juvenile salmon and steelhead stranded on gravel bars are frequently counted to get an idea of how many fry are killed by a fluctuating flow associated with hydropower generation. One constructive criticism of this method is that a large number of stranded (dead) fry could be picked up and eaten by birds or mammals before human observers can get an accurate count at daylight. A small experiment was done to evaluate whether or not stranded fry were eaten before they could be counted.

The experiment was completed in two days and was not intended to be scrutinized with statistics or published in a scientific journal. Rather, the experiment was intended to examine something we were curious about, and make a first approximation as to the extent of the problem.

(b) Approach and Methodology

The experiment was designed to detect the presence of early-morning scavengers or predators feeding on stranded fry along gravel bars and potholes. The term scavenger is less confusing to use because the stranded fry are usually dead soon after stranding and, therefore, have no means of escape.

Each of the six gravel bars had 9 to 15 dead fry placed on them between 2 and 4 a.m. on two different nights during April 1986. The fry used in these tests consisted of dead fry collected from gravel bars the day preceding each test so they were representative of what scavengers would see (or smell) along the Skagit River. The experiments were conducted on April 10 and 11 in conjunction with the gravel bar stranding studies.

Fry were placed in a straight line along each gravel bar, with 2 feet between each dead fry. No attempt was made to conceal the fry, and they were placed on whatever substrate was representative of the gravel bar. Dead fry were placed below that night's high waterline, and above the low waterline that would eventually be reached by mid-morning. All fry were placed on the bars during complete darkness.

Dead fry were checked every 2 hours after being placed on the gravel bar to see whether or not they had been eaten by scavengers. The first check was made around daybreak, which was about 5:30 am and again at 8:00 am. Gravel bar stranding observers were on the gravel bars from 5:30 am until their data collection was completed.

(5) Fry Recruitment in Potholes

(a) Objectives and General Description of Field Studies

Concern over the effects of dam regulated flow fluctuations on salmon and steelhead production in the Skagit River has prompted cooperative studies between Seattle City Light, Washington Department of Fisheries and other agencies since 1969. Studies by Thompson (1970) and Phinney (1974) attempted to define operational regimes least detrimental to downstream fish populations. In 1979, relicensing proceedings of three existing hydroelectric facilities prompted further investigations relating discharge to fish survival. Representatives of City Light, Washington State Department of Fisheries and Wildlife, Skagit System Indian Tribes, U.S. Fish and Wildlife Service, and National Marine Fisheries Service agreed on a two-year interim agreement regulating ramping rate and flow magnitude in the Skagit River.

As part of this agreement, Stober (1982) studied the effects of flow fluctuations on spawning behavior, egg deposition efficiency, incubation, fry survival to emergence and stranding of salmon and steelhead fry. In continuation of these studies, R. W. Beck and Associates was retained to investigate the relationship between flow fluctuations and stranding from spring of 1985 to spring of 1986. As an extension to this work, Troutt and Pauley (1986) examined fry residency time in potholes exposed to dewatering by downramping events. His findings show chinook fry remain an average of 2.4 days in potholes and, therefore, are susceptible to multiple downramping events. Furthermore, this work demonstrated that the daily sample of fry trapped in potholes does not undergo a complete exchange of fry between downramping events since many fry occupy a pothole for more than one flow fluctuation cycle. These latter findings raised questions concerning numbers of fry at risk to pothole stranding.

Potholes that have gone completely dry will strand all fry trapped inside. The objective of the study was to determine how quickly an empty (contains no fry) pothole recruits fry. Recruitment in this context is defined as fry that move into and remain in a pothole.

(b) Approach

All salmon fry were removed from selected potholes, placed in a bucket, counted and released into the main river or side channel at a point downstream of the test pothole. This practice would in theory eliminate the chance of these fry being recruited back into the same pothole during subsequent downramp events. An electroshocker, Smith Root Type XI, was again used to remove all fry from each pothole tested following a designated test interval. Test lengths varied from one to five days. Electrofishing began at daybreak to minimize the loss of fry to scavenging birds (Stober et al., 1982). Study potholes were cleared of fry beginning at the furthest upstream pothole and working downstream. The number of fry removed from each pothole after a predetermined test period was used to estimate the recruitment rate of each pothole.

The sampling routine used during this study was developed to take advantage of the test flow pattern designed for the gravel bar stranding study. Tests took place from March 13 to April 14, 1986. A rotation schedule for emptying potholes was made by dividing the river into five areas. Area One, for example, includes 7 potholes located from Bacon Creek to Marblemount. If this area was scheduled for a one-day test, the potholes would be emptied of fry on this day and again the following morning, allowing potholes to connect with the main river once. Generally, three areas per day could be sampled before upramping flows covered the pothole areas. Area One would then be allowed to recruit for 2-3 days depending on the schedule. Similarly, potholes in other areas are all connecting and disconnecting with the test flow cycle. Each pothole's recruitment performance was monitored with respect to beginning flows prior to and including the sampling date.

The field data were arranged according to the level of downramp beginning flow used prior to fry recruitment sampling. There were four beginning flow levels used; 5,000, 5,500, 7,000, and 7,500 cfs. The data associated with these four flows were clustered into two levels of beginning flow; high beginning flow (7,500 and 7,000 cfs) and low beginning flow (5,500 and 5,000 cfs). Within each of these two beginning flow data-sets another descriptive factor, called "N-days", was created to describe the flow history preceding a downramping test in terms of the number of low beginning flow downramps that occurred prior to test day. N-days was defined as the number of successive low beginning flow downramps that occurred prior to pothole sampling date. For example, if on March 15, a pothole was sampled and the beginning flow of the downramp prior to this pothole sampling date was a low beginning flow (5,000 or 5,500 cfs); the N-days would be the number of successive beginning flow downramps with a low beginning flow. Therefore, if March 13-14 were low beginning flows and March 12 was a high beginning flow the N-days would be two (2).

The number of fry electroshocked from individual potholes in conjunction with their N-day values will provide a means for comparison between the average number of fry trapped with high versus low beginning flows. Secondly, within each beginning flow category a comparison of the average stranded versus N-days can be made to determine if beginning flow history patterns affect the number of fry trapped in potholes.

(c) Streamflow

Seattle City Light regulated test flows according to a requested test pattern designed by R. W. Beck and Associates. Test flows involved a combination of amplitudes, ramping rates and endflows. Endflows were measured at the Marblemount gauge. Minimum endflows were set at 3,000 and 3,500 cfs depending on the test. Amplitudes were set at 2,000 and 4,000 cfs and varied according to the test. Thus, beginning flows varied from 5,000 to 7,500 cfs. For example, if a particular test required a 3,000 cfs endflow and a 4,000 cfs amplitude, the beginning flow was 7,000 cfs at Marblemount. The potholes selected for this study became disconnected from the Skagit River somewhere between the beginning and endflows used during the study. If endflows were greater than 3,500 cfs, some of these potholes would remain connected to the main river, thus eliminating them from a study rotation.

To minimize fry mortality, downramping was conducted during the night (Woodin, 1984). Upramping began at 0700 requiring the electrofishing be completed without delay to avoid pothole inundation.

(d) Site Selection

During the spring of 1985, R. W. Beck and Associates gathered detailed measurements concerning connection flows for potholes located on the upper Skagit River between Bacon Creek and Rockport. Potholes used for the recruitment study were selected using this flow connection data in conjunction with the following criteria: (1) a pothole must be actively connecting and disconnecting within the prescribed test flow parameters; (2) a pothole must be of manageable proportions, affording the removal of all fry within a reasonable period of time; (3) a pothole must retain enough water to support fry for the duration of the low flow period. Thirty-six potholes were selected and used to evaluate fry recruitment. These potholes varied in size, cover, depth and substrate, and were selected to represent the various pothole types found in this section of the Skagit.

(e) Data Analysis

Analysis of variance by ranks (Kruskal-Wallis test) was applied to the data for number of fry recruited. Recruitment was compared using the number of consecutive day tests conducted with a low beginning flow prior to the sampling date. Tests involved two different beginning flows which were placed into separate subgroups where: AMP=1 is the low beginning flow test and AMP=2 is the high beginning flow test.

SECTION IV

RESULTS OF THE SPRING 1985 POTHOLE TRAPPING AND STRANDING STUDIES

1. PHYSICAL AND BIOLOGICAL DATA FOR POTHOLES

a. Results

Chinook, coho, chum, and pink fry, and steelhead juveniles were found trapped and/or stranded in potholes within the study area on the Skagit River. Greater detail regarding temporal species composition within potholes is presented later in this section as part of the results for pothole residency timing of salmon fry and steelhead juveniles.

One of the primary objectives of the pothole studies was to collect pothole specific data relating to their biological, physical, and hydrological characteristics. These data are used to provide a complete inventory of potholes on the Skagit River and can also be used to help explain why certain potholes trap and/or strand fry.

There were a total of 232 potholes from which data were collected during the course of these studies. Table 10 summarizes the most important characteristics of each of these potholes. The field data used to construct Table 10 are found in Appendix D of this report.

The following data are presented for each pothole:

(1) Pothole Location
(2) Pothole Number
(3) Average Fry Trapped
(4) Average Fry Stranded
(5) Connection Flow
(6) Dry Flow
(7) Source Of Connect and Dry Flows (method used to determine)
(8) Maximum Depth (while disconnected)
(9) Substrate Type
(10) Cover Type

Table 11 summarizes some of the most interesting pothole information as it relates to trapping and stranding of salmon fry. Eighty-one percent (188) of the potholes were located in the lower reach of the study area. Forty-one percent of the lower reach potholes trapped fry during the study. Trapped fry numbers ranged from 0 to 128. Twenty percent of the potholes in this reach also stranded fry, with the average number stranded per pothole ranging up to 14 fry.

Nineteen percent of the potholes were located in the middle reach of the Skagit River study area. Thirty percent of these potholes trapped fry. Trapped fry numbers ranged from 0 to 137 per pothole. Seven percent of the

TABLE 10 POTHOLE CHARACTERISTICS EXPRESSED AS NUMBERS OF FRY TRAPPED AND STRANDED, CONNECTION AND DRY FLOWS, AND SUBSTRATE AND COVER TYPE FOR POTHOLES LOCATED BETWEEN ROCKPORT AND COPPER CREEK

POTHOLE LOCATION CODE	POTHOLE NUMBER	TOTAL NUMBER OF TRAPPED FRY SUMMED FOR ALL OBSERVATIONS	TOTAL NUMBER OF STRANDED FRY SUMMED FOR ALL OBSERVATIONS	NUMBER OF OBSERVATIONS AT POTHOLE	PREDICTED CONNECTION FLOW AT MARBLEMOUNT GAGE (CFS)	MAXIMUM OBSERVED DEPTH (FT)	PREDICTED POTHOLE DRY FLOW AT MARBLEMOUNT GAGE (1) (CFS)	SUBSTRATE CODE (2) M = MUD S = SAND G = GRAVEL C = COBBLE	COVER PRESENT OR NOT Y = YES N = NO	SOURCE OF HYDRAULIC FLOW DATA (SEE (3) BELOW)
1	1	31	21	14	4375	0.70	4880	-0-	-0-	10
1	11	0	0	3	4665	0.50	3700	-0-	-0-	20
1	12	0	1	3	3750	0.90	2244	-0-	-0-	23
1	13	1	0	7	4375	0.50	3490	-0-	-0-	10
1	13A	0	0	3	4910	0.30	-3470	-0-	-0-	20
1	14	90	0	8	4360	1.40	2470	-0-	-0-	10
1	15	45	0	7	4360	0.50	1860	-0-	-0-	11
1	16A	1	0	4	3660	0.20	3700	-0-	-0-	10
1	17	48	4	5	4050	0.90	2500	-0-	-0-	10
1	17A	0	4	6	4430	0.20	-4430	-0-	-0-	10
1	17B	0	0	3	4880	0.20	-4880	-0-	-0-	20
1	18	14	0	3	4165	0.70	2909	-0-	-0-	11
1	19	0	1	2	3995	0.30	3560	-0-	-0-	10
1	1A	0	2	10	5740	0.10	-5740	-0-	-0-	10
1	2	0	0	1	4135	0.00	4344	-0-	-0-	23
1	20	5	0	4	3815	1.20	3560	-0-	-0-	10
1	22	0	0	3	5740	0.00	-5740	-0-	-0-	10
1	23	0	0	3	5740	0.00	-5740	-0-	-0-	20
1	3	7	7	7	4790	1.00	3890	-0-	-0-	10
1	4	0	0	12	-0-	0.00	-5740	-0-	-0-	10
1	5	0	0	2	4430	0.00	-4430	-0-	-0-	20
1	6	0	3	11	4880	0.60	4670	-0-	-0-	10
1	7	0	0	4	5210	0.00	5210	-0-	-0-	25
1	7A	0	0	7	4270	0.00	4270	-0-	-0-	23
1	8	1	0	5	4360	0.70	3675	-0-	-0-	10
1	9	0	0	1	4045	0.30	2920	-0-	-0-	23
1	A	0	0	1	4135	1.30	-2500	-0-	-0-	201
1	B	0	0	2	4490	0.10	-4490	-0-	-0-	20
1	C	0	0	2	4430	0.00	-4430	-0-	-0-	20

NOTE:

SEE FIGURE 1 FOR POTHOLE LOCATION CODES.

(1) THE NEGATIVE SYMBOL INDICATES THAT THE ACTUAL POTHOLE DRYFLOW IS SOMEWHERE BELOW THE VALUE SHOWN.

(2) -0- IN SUBSTRATE OR COVER COLUMN INDICATES NO DATA.

(3) SOURCE CODE IS A CODE THAT DESCRIBES THE SOURCE OF EACH POTHOLE CONNECTION AND DRY FLOW ESTIMATE.

SOURCE CODE:

INSAMPLE/RANDOM POTHOLES : 1 #
ALL OTHER POTHOLES : 2 #
DRYFLOW/CONNECT FLOW ESTIMATES (DERIVED USING METHODS ILLUSTRATED BY FIGURES 2 AND 3) : # 0
DRYFLOW BY REGRESSION : # 1
CONNECT FLOW FROM JONES AND STOKES, INC. : # 2
DRYFLOW FROM JONES AND STOKES, INC. : # 3
1 # AND # 2 # : # 4
2 # AND # 3 # : # 5
ROUGH ESTIMATE OF DRYFLOW (FROM DATA OBSERVATION) : # # 1

SUBSTRATE CODE:

S = SAND
G = GRAVEL
C = COBBLE
M = MUD

POTHOLE LOCATION CODE	POTHOLE NUMBER	TOTAL NUMBER OF TRAPPED FRY SUMMED FOR ALL OBSERVATIONS	TOTAL NUMBER OF STRANDED FRY SUMMED FOR ALL OBSERVATIONS	NUMBER OF OBSERVATIONS AT POTHOLE	PREDICTED CONNECTION FLOW AT MARBLEMOUNT GAGE (CFS)	MAXIMUM OBSERVED DEPTH (FT)	PREDICTED POTHOLE DRY FLOW AT MARBLEMOUNT GAGE (1) (CFS)	SUBSTRATE CODE (2) M = MUD S = SAND G = GRAVEL C = COBBLE	COVER PRESENT OR NOT Y = YES N = NO	SOURCE OF HYDRAULIC FLOW DATA (SEE (3) BELOW)
1	D	0	0	5	5740	0.00	-5740	-0-	-0-	20
2	11	10	0	4	4180	0.40	3560	S	Y	14
2	12	4	0	15	4385	0.50	4360	S	Y	10
2	2	460	0	13	4385	1.90	396	G	Y	11
2	3	631	0	9	4175	1.10	1685	G	Y	11
2	4	0	0	0	3560	1.70	4030	-0-	-0-	11
2	5	20	2	15	5740	1.20	3610	G	Y	10
2	A	1	1	4	3995	0.30	3525	-0-	N	10
2	C	0	0	3	3840	0.70	3008	S	Y	20
2	F	13	0	3	3560	0.80	-4000	C	Y	11
2	G	0	0	1	3655	1.50	-2500	G	Y	201
2	H	0	0	2	4064	0.80	-3000	S	N	201
2	I	35	0	1	4053	1.10	1953	S	N	12
2	N	0	0	7	4335	1.00	4120	S	Y	21
4	11	20	0	14	5325	1.50	-2550	S	Y	101
4	11B	140	12	13	4910	0.50	3560	-0-	-0-	10
4	12	0	0	14	5740	0.20	-5740	S	N	10
4	15	0	0	2	4288	1.00	-3840	G	Y	20
4	5	0	0	14	4730	1.40	2670	G	Y	11
4	6	0	0	1	3840	-0-	-1000	-0-	-0-	201
4	7	0	0	15	5740	1.70	1515	C	N	21
4	8	0	0	15	5740	0.20	-5740	S	Y	10
4	9	0	0	4	-0-	0.30	4204	-0-	-0-	21
4	C	0	0	1	-0-	3.00	-2500	-0-	N	201
5	1	207	0	15	5740	2.80	-2570	S	N	10
5	10	0	0	0	4470	1.20	3152	S	Y	11
5	11	1	0	8	4175	1.20	4665	G	N	12
5	12	357	0	15	5740	1.60	2470	S	Y	10
5	13	2	5	12	5740	0.20	-5740	-0-	-0-	10
5	14	21	0	14	5740	0.70	4665	S	Y	10
5	16	0	0	2	5740	0.40	5014	G	Y	20
5	17	6	0	12	5310	0.30	3525	S	Y	10
5	18	0	0	3	5740	0.00	-5740	-0-	-0-	20
5	19	0	0	5	5740	1.60	4738	-0-	-0-	21
5	2	186	0	15	5740	1.80	2570	S	N	11
5	3	2	0	15	5740	1.10	2244	S	N	21
5	4	2	1	15	5740	0.80	-3165	S	Y	10

NOTE:

SEE FIGURE 1 FOR POTHOLE LOCATION CODES.

(1) THE NEGATIVE SYMBOL INDICATES THAT THE ACTUAL POTHOLE DRYFLOW IS SOMEWHERE BELOW THE VALUE SHOWN.

(2) -0- IN SUBSTRATE OR COVER COLUMN INDICATES NO DATA.

(3) SOURCE CODE IS A CODE THAT DESCRIBES THE SOURCE OF EACH POTHOLE CONNECTION AND DRY FLOW ESTIMATE.

SOURCE CODE:

INSAMPLE/RANDOM POTHOLES : 1 #
ALL OTHER POTHOLES : 2 #
DRYFLOW/CONNECT FLOW ESTIMATES (DERIVED USING METHODS ILLUSTRATED BY FIGURES 2 AND 3) : # 0
DRYFLOW BY REGRESSION : # 1
CONNECT FLOW FROM JONES AND STOKES, INC. : # 2
DRYFLOW FROM JONES AND STOKES, INC. : # 3
1 # AND # 2 # : # 4
2 # AND # 3 # : # 5
ROUGH ESTIMATE OF DRYFLOW (FROM DATA OBSERVATION) : # # 1

SUBSTRATE CODE:

S = SAND
G = GRAVEL
C = COBBLE
M = MUD

POTHOLE LOCATION CODE	POTHOLE NUMBER	TOTAL NUMBER OF TRAPPED FRY SUMMED FOR ALL OBSERVATIONS	TOTAL NUMBER OF STRANDED FRY SUMMED FOR ALL OBSERVATIONS	NUMBER OF OBSERVATIONS AT POTHOLE	PREDICTED CONNECTION FLOW AT MARBLEMOUNT GAGE (CFS)	MAXIMUM OBSERVED DEPTH (FT)	PREDICTED POTHOLE DRY FLOW AT MARBLEMOUNT GAGE (1) (CFS)	SUBSTRATE CODE (2) M = MUD S = SAND G = GRAVEL C = COBBLE	COVER PRESENT OR NOT Y = YES N = NO	SOURCE OF HYDRAULIC FLOW DATA (SEE (3) BELOW)
5	5	39	0	14	5740	1.80	-2434	S	Y	10
5	6	9	0	15	5740	1.60	2510	S	N	11
5	7	30	0	4	4880	1.70	447	G	N	21
5	8	0	0	4	4880	0.80	3538	G	N	20
6	1	0	9	14	4790	0.60	5325	S	N	10
6	10	960	31	7	3470	2.40	2425	C	Y	11
6	11	132	104	11	4895	0.60	4110	G	N	10
6	13	0	0	0	4910	0.20	4200	G	Y	10
6	13A	181	0	4	3565	1.40	-3000	C	Y	101
6	14	2	9	4	4910	0.30	4140	S	Y	10
6	15	0	0	2	5740	1.00	-5740	S	Y	20
6	16	0	0	9	4880	1.00	-4880	S	N	20
6	17	0	0	3	4880	0.00	-4880	-0-	-0-	20
6	19	0	0	1	4430	0.00	-4430	-0-	-0-	20
6	2	0	0	6	5740	0.50	4613	S	Y	20
6	20	0	0	2	4490	1.00	-4490	G	Y	20
6	3	0	0	15	4910	0.50	4200	G	N	10
6	4	29	0	10	5015	1.00	3560	S	N	10
6	5	4	0	15	5740	1.00	3610	G	Y	10
6	5A	0	0	15	5740	0.40	4895	G	N	10
6	6	46	0	10	5740	0.80	3610	G	N	10
6	7	0	0	13	5740	0.70	4895	C	N	10
6	8	0	0	7	5740	0.70	3394	S	N	21
6	8A	0	0	4	4260	0.60	3560	S	N	21
6	9	1	7	6	4770	1.70	2815	C	N	11
7	1	0	0	9	4880	1.20	1217	-0-	-0-	21
7	10	0	0	8	4880	0.00	-4910	-0-	-0-	20
7	11	0	0	7	4880	0.00	-4880	-0-	-0-	20
7	2	0	0	14	5740	1.30	2571	-0-	-0-	11
7	3	0	0	10	4880	0.00	-4910	-0-	-0-	20
7	4	0	0	5	4880	0.00	-4880	-0-	-0-	20
7	5	0	0	14	5740	1.50	2036	-0-	-0-	11
7	6	0	0	0	4497	0.30	3525	-0-	-0-	10
7	7	8	2	10	4175	0.80	3660	-0-	-0-	10
7	8	0	0	14	5740	0.00	-5740	-0-	-0-	10
7	X	5	42	3	4895	0.70	3490	-0-	-0-	10
7	Y	1	7	2	3790	0.30	3675	-0-	-0-	20

NOTE:

SEE FIGURE 1 FOR POTHOLE LOCATION CODES.

(1) THE NEGATIVE SYMBOL INDICATES THAT THE ACTUAL POTHOLE DRYFLOW IS SOMEWHERE BELOW THE VALUE SHOWN.

(2) -0- IN SUBSTRATE OR COVER COLUMN INDICATES NO DATA.

(3) SOURCE CODE IS A CODE THAT DESCRIBES THE SOURCE OF EACH POTHOLE CONNECTION AND DRY FLOW ESTIMATE.

SOURCE CODE:

INSAMPLE/RANDOM POTHOLES : 1 :
ALL OTHER POTHOLES : 2 :
DRYFLOW/CONNECT FLOW : : 0
ESTIMATES (DERIVED USING METHODS ILLUSTRATED BY FIGURES 2 AND 3)
DRYFLOW BY REGRESSION : : 1
CONNECT FLOW FROM JONES AND STOKES, INC. : : 2
DRYFLOW FROM JONES AND STOKES, INC. : : 3
: 1 : AND : 2 : : : 4
: 2 : AND : 3 : : : 5
ROUGH ESTIMATE OF DRYFLOW (FROM DATA OBSERVATION) : : : 1

SUBSTRATE CODE:

S = SAND
G = GRAVEL
C = COBBLE
M = MUD

POTHOLE LOCATION CODE	POTHOLE NUMBER	TOTAL NUMBER OF TRAPPED FRY SUMMED FOR ALL OBSERVATIONS	TOTAL NUMBER OF STRANDED FRY SUMMED FOR ALL OBSERVATIONS	NUMBER OF OBSERVATIONS AT POTHOLE	PREDICTED CONNECTION FLOW AT MARBLEMOUNT GAGE (CFS)	MAXIMUM OBSERVED DEPTH (FT)	PREDICTED POTHOLE DRY FLOW AT MARBLEMOUNT GAGE (1) (CFS)	SUBSTRATE CODE (2) M = MUD S = SAND G = GRAVEL C = COBBLE	COVER PRESENT OR NOT Y = YES N = NO	SOURCE OF HYDRAULIC FLOW DATA (SEE (3) BELOW)
7	2	0	0	2	3790	0.00	-3790	-0-	-0-	20
8	1	0	0	1	4880	0.00	-4880	-0-	-0-	20
8	2	0	0	1	4880	0.00	-4880	-0-	-0-	20
8	3	0	0	1	4880	0.00	-4880	-0-	-0-	20
8	4	0	0	1	4880	0.00	-4880	-0-	-0-	20
8	7	0	0	1	4880	0.00	-4880	-0-	-0-	20
8	8	0	0	1	4880	0.00	-4880	-0-	-0-	20
10	1	27	0	7	4260	1.30	3649	-0-	-0-	11
10	10	40	0	4	4655	1.90	-1932	-0-	-0-	101
10	12	3	0	3	4550	1.50	-3500	-0-	-0-	201
10	13	17	0	7	4585	1.10	3193	-0-	-0-	11
10	14	30	5	7	4585	1.00	3975	-0-	-0-	10
10	15	1738	0	14	5150	2.80	3243	-0-	-0-	11
10	16	2	3	6	4840	0.30	3725	-0-	-0-	10
10	17	0	0	0	4600	1.50	-3000	-0-	-0-	101
10	2	0	0	1	5145	1.10	-2500	-0-	-0-	201
10	26	0	0	1	5145	0.60	-3500	-0-	-0-	201
10	27	0	0	1	5145	0.00	-4550	-0-	-0-	20
10	3	0	0	0	4840	0.80	-3000	-0-	-0-	101
10	4	35	0	5	5310	1.80	-4550	-0-	-0-	20
10	5	0	0	2	5145	1.80	-2500	-0-	-0-	20
10	6	0	0	2	5145	1.10	-4500	-0-	-0-	20
10	7	0	0	1	5145	0.70	3514	-0-	-0-	23
10	8	0	0	2	5085	1.30	-2500	-0-	-0-	201
10	9	0	0	3	5325	1.10	3610	-0-	-0-	23
10	A	3	1	5	4190	1.40	-3562	-0-	-0-	10
10	B	0	0	3	4550	1.70	2094	-0-	-0-	23
10	C	0	0	1	4500	0.00	-4550	-0-	-0-	20
10	D	0	0	2	3653	1.80	2710	-0-	-0-	23
10	E	50	0	2	3653	1.40	-3000	-0-	-0-	201
10	F	0	4	7	5310	0.50	-4880	-0-	-0-	10
10	G	8	0	6	4585	1.10	2867	-0-	-0-	11
10	H	1	0	3	4550	1.50	4344	-0-	-0-	20
10	J	0	5	1	3925	0.70	-2500	-0-	-0-	101
11	10	0	0	2	4490	0.00	-4490	G	N	20
11	A	97	0	5	4940	1.10	2495	G	Y	11
11	B	428	0	4	5135	2.70	4030	G	Y	11

NOTE:

SEE FIGURE 1 FOR POTHOLE LOCATION CODES.

(1) THE NEGATIVE SYMBOL INDICATES THAT THE ACTUAL POTHOLE DRYFLOW IS SOMEWHERE BELOW THE VALUE SHOWN.

(2) -0- IN SUBSTRATE OR COVER COLUMN INDICATES NO DATA.

(3) SOURCE CODE IS A CODE THAT DESCRIBES THE SOURCE OF EACH POTHOLE CONNECTION AND DRY FLOW ESTIMATE.

SOURCE CODE:

INSAMPLE/RANDOM POTHOLES : 1 *
ALL OTHER POTHOLES : 2 *
DRYFLOW/CONNECT FLOW : * 0
ESTIMATES (DERIVED USING METHODS ILLUSTRATED BY FIGURES 2 AND 3)
DRYFLOW BY REGRESSION : * 1
CONNECT FLOW FROM JONES AND STOKES, INC. : * 2
DRYFLOW FROM JONES AND STOKES, INC. : * 3
* 1 * AND * 2 * : * 4
* 2 * AND * 3 * : * 5
ROUGH ESTIMATE OF DRYFLOW (FROM DATA OBSERVATION) : * * 1

SUBSTRATE CODE:

S = SAND
G = GRAVEL
C = COBBLE
M = MUD

POTHOLE LOCATION CODE	POTHOLE NUMBER	TOTAL NUMBER OF TRAPPED FRY SUMMED FOR ALL OBSERVATIONS	TOTAL NUMBER OF STRANDED FRY SUMMED FOR ALL OBSERVATIONS	NUMBER OF OBSERVATIONS AT POTHOLE	PREDICTED CONNECTION FLOW AT MARBLEMOUNT GAGE (CFS)	MAXIMUM OBSERVED DEPTH (FT)	PREDICTED POTHOLE DRY FLOW AT MARBLEMOUNT GAGE (1) (CFS)	SUBSTRATE CODE (2) M = MUD S = SAND G = GRAVEL C = COBBLE	COVER PRESENT OR NOT Y = YES N = NO	SOURCE OF HYDRAULIC FLOW DATA (SEE (3) BELOW)
12	10	0	0	11	4200	0.60	4335	-0-	-0-	10
12	11	71	0	5	3825	1.70	3193	-0-	-0-	11
12	12	0	0	0	4290	0.00	-4490	-0-	-0-	10
12	13	0	0	1	4430	0.00	-4490	-0-	-0-	20
12	14	0	0	1	4430	0.00	-4430	-0-	-0-	20
12	16	0	0	1	4430	0.00	-4430	-0-	-0-	20
12	1A	150	8	2	4040	0.80	1896	-0-	-0-	103
12	1B	123	0	2	3675	1.80	3100	-0-	-0-	11
12	1C	20	0	3	4335	1.90	3162	-0-	-0-	11
12	1D	2	6	10	5150	1.20	4075	-0-	-0-	10
12	1E	370	1	10	5150	2.20	-2510	-0-	-0-	10
12	5	20	9	5	5135	0.20	3065	-0-	-0-	10
12	6	21	0	5	5740	0.90	-3790	-0-	-0-	20
12	8	0	0	4	5740	0.40	4400	-0-	-0-	20
12	A	0	0	1	3370	0.90	3370	-0-	-0-	20
13	10	0	0	9	4880	0.50	3465	-0-	-0-	20
13	11	0	26	7	4360	0.70	3420	-0-	-0-	10
13	12	17	0	13	5740	0.80	3925	-0-	-0-	10
13	13	0	0	4	5740	0.10	-5740	-0-	-0-	20
13	16	0	0	6	4910	0.00	-4880	-0-	-0-	20
13	3	6	0	3	4290	0.50	4068	-0-	-0-	31
13	4	0	0	5	5740	0.60	4288	-0-	-0-	21
13	5	2	0	13	5740	1.00	3660	-0-	-0-	10
13	7	192	1	11	5740	1.40	4045	-0-	-0-	10
13	8	0	0	0	5740	1.20	3785	-0-	-0-	13
13	9	64	0	5	4790	1.00	1057	-0-	-0-	20
13	A	8	3	3	3565	1.00	-2430	-0-	-0-	10
13	B	53	15	3	3565	1.00	-2430	-0-	-0-	10
13	C	16	2	2	3790	0.80	-3790	-0-	-0-	10
13	D	0	5	1	3790	0.00	-3790	-0-	-0-	10
14	A	21	22	10	4910	0.60	4360	S	N	10
14	B	2	0	4	4655	0.90	3547	G	N	11
16	A	0	0	1	4290	1.00	4290	S	N	20
16	B	0	0	0	4290	0.50	2630	G	Y	13
16	C	0	0	0	4290	0.20	2630	S	Y	13
17	A	75	0	1	-0-	0.40	2149	S	N	13
17	B	125	2	1	-0-	0.30	2149	S	N	13

NOTE:

SEE FIGURE 1 FOR POTHOLE LOCATION CODES.

(1) THE NEGATIVE SYMBOL INDICATES THAT THE ACTUAL POTHOLE DRYFLOW IS SOMEWHERE BELOW THE VALUE SHOWN.

(2) -0- IN SUBSTRATE OR COVER COLUMN INDICATES NO DATA.

(3) SOURCE CODE IS A CODE THAT DESCRIBES THE SOURCE OF EACH POTHOLE CONNECTION AND DRY FLOW ESTIMATE.

SOURCE CODE:

INSAMPLE/RANDOM POTHOLES : 1 *
ALL OTHER POTHOLES : 2 *
DRYFLOW/CONNECT FLOW : * 0
ESTIMATES (DERIVED USING METHODS ILLUSTRATED BY FIGURES 2 AND 3)
DRYFLOW BY REGRESSION : * 1
CONNECT FLOW FROM JONES AND STOKES, INC. : * 2
DRYFLOW FROM JONES AND STOKES, INC. : * 3
* 1 * AND * 2 * : * 4
* 2 * AND * 3 * : * 5
ROUGH ESTIMATE OF DRYFLOW : * * 1
(FROM DATA OBSERVATION)

SUBSTRATE CODE:

S = SAND
G = GRAVEL
C = COBBLE
M = MUD

POTHOLE LOCATION CODE	POTHOLE NUMBER	TOTAL NUMBER OF TRAPPED FRY SUMMED FOR ALL OBSERVATIONS	TOTAL NUMBER OF STRANDED FRY SUMMED FOR ALL OBSERVATIONS	NUMBER OF OBSERVATIONS AT POTHOLE	PREDICTED CONNECTION FLOW AT MARBLEMOUNT GAGE (CFS)	MAXIMUM OBSERVED DEPTH (FT)	PREDICTED POTHOLE DRY FLOW AT MARBLEMOUNT GAGE (1) (CFS)	SUBSTRATE CODE (2) M = MUD S = SAND G = GRAVEL C = COBBLE	COVER PRESENT OR NOT Y = YES N = NO	SOURCE OF HYDRAULIC FLOW DATA (SEE (3) BELOW)
18	A	0	0	0	4290	1.80	2773	C	N	13
18	B	0	0	0	4290	1.90	-3030	C	Y	101
18	C	0	0	2	5740	0.00	-5740	C	Y	20
18	D	0	0	2	5740	2.00	-5740	-0-	-0-	20
18	E	0	0	2	5740	1.00	-5740	C	N	20
18	F	0	0	2	5740	1.00	-5740	-0-	Y	20
18	G	0	0	2	5740	2.00	-5740	-0-	-0-	20
19	H	0	0	1	4430	0.00	-4430	-0-	N	20
19	I	0	0	1	4430	4.00	-4430	G	N	20
19	J	0	0	1	4430	1.00	-4430	G	N	20
19	K	0	0	3	5740	0.00	-5740	-0-	N	20
21	A	29	0	2	3575	1.90	-2550	C	Y	10
21	B	0	0	0	3490	1.30	-2550	C	Y	101
21	C	0	0	1	5740	1.00	-5740	-0-	Y	20
21	D	0	0	3	4910	1.00	-5740	-0-	Y	20
21	E	0	0	2	5740	1.30	-5740	-0-	Y	20
21	F	0	0	1	5740	2.00	-5740	-0-	Y	20
21	G	0	0	1	5740	2.50	-5740	C	Y	20
21	H	0	0	1	5740	1.00	-5740	C	Y	20
21	I	0	0	1	5740	1.60	-5740	C	Y	20
22	1	0	0	1	4910	0.00	-4910	-0-		20
22	B	35	0	1	-0-	0.90	-3030	-0-	-0-	101
22	C	0	0	1	3466	0.60	-3466	-0-	-0-	20
23	1	7	0	2	4910	0.70	2550	C	Y	10
23	11	0	0	1	5740	2.00	-5740	-0-	Y	20
23	12	0	0	1	5520	0.30	-5740	S	Y	20
23	14	0	0	1	5740	0.00	-5740	G	Y	20
23	2	0	0	1	5310	0.60	3324	G	Y	23
23	3	0	0	7	4910	0.00	2857	C	Y	21
23	4	259	0	4	5565	1.70	-2430	C	N	10
23	5	1	0	5	5565	0.40	4200	C	N	10
23	6	0	0	6	5740	0.70	3978	C	Y	20
23	7	0	0	5	5520	0.70	3886	G	Y	21
23	9	0	0	1	5740	1.50	3052	-0-	Y	23
23	B	137	0	1	4910	0.90	3052	S	Y	10
23	C	57	0	2	4940	1.40	-2530	S	Y	101
23	E	0	0	0	3490	0.10	3490	G	N	10

NOTE:

SEE FIGURE 1 FOR POTHOLE LOCATION CODES.

(1) THE NEGATIVE SYMBOL INDICATES THAT THE ACTUAL POTHOLE DRYFLOW IS SOMEWHERE BELOW THE VALUE SHOWN.

(2) -0- IN SUBSTRATE OR COVER COLUMN INDICATES NO DATA.

(3) SOURCE CODE IS A CODE THAT DESCRIBES THE SOURCE OF EACH POTHOLE CONNECTION AND DRY FLOW ESTIMATE.

SOURCE CODE:

INSAMPLE/RANDOM POTHOLES : 1 #
ALL OTHER POTHOLES : 2 #
DRYFLOW/CONNECT FLOW : # 0
ESTIMATES (DERIVED USING METHODS ILLUSTRATED BY FIGURES 2 AND 3)
DRYFLOW BY REGRESSION : # 1
CONNECT FLOW FROM JONES AND STOKES, INC. : # 2
DRYFLOW FROM JONES AND STOKES, INC. : # 3
1 # AND # 2 # : # 4
2 # AND # 3 # : # 5
ROUGH ESTIMATE OF DRYFLOW : # # 1
(FROM DATA OBSERVATION)

SUBSTRATE CODE:

S = SAND
G = GRAVEL
C = COBBLE
M = MUD

POTHOLE LOCATION CODE	POTHOLE NUMBER	TOTAL NUMBER OF TRAPPED FRY SUMMED FOR ALL OBSERVATIONS	TOTAL NUMBER OF STRANDED FRY SUMMED FOR ALL OBSERVATIONS	NUMBER OF OBSERVATIONS AT POTHOLE	PREDICTED CONNECTION FLOW AT MARBLEMOUNT GAGE (CFS)	MAXIMUM OBSERVED DEPTH (FT)	PREDICTED POTHOLE DRY FLOW AT MARBLEMOUNT GAGE (1) (CFS)	SUBSTRATE CODE (2) M = MUD S = SAND G = GRAVEL C = COBBLE	COVER PRESENT OR NOT Y = YES N = NO	SOURCE OF HYDRAULIC FLOW DATA (SEE (3) BELOW)
24	1	0	0	1	3660	0.00	-3466	S	Y	22
26	1	48	12	12	4295	2.40	3525	C	N	10
26	11	0	0	2	4490	0.00	-4490	-0-	Y	20
26	12	0	0	2	4490	0.00	-4490	-0-	-0-	20
26	2	235	0	7	4185	0.90	3210	C	N	10
26	3	0	0	4	4910	1.30	2168	-0-	Y	21
26	4	215	1	13	4910	3.70	-2430	G	Y	10
26	5	0	0	2	4490	0.00	-4490	-0-	Y	20
26	6	0	0	4	4880	0.50	3660	-0-	N	20
26	7	0	0	4	4880	1.10	3560	-0-	Y	20
26	A	58	5	4	4140	0.60	4490	G	Y	10
26	C	15	0	3	4120	1.20	-3000	S	N	201
26	D	0	0	1	4040	0.80	3052	G	N	23
27	A	38	0	4	3560	0.40	2430	S	Y	10
27	F	0	0	0	3526	0.20	3560	S	N	10
27	G	0	0	4	3660	0.50	2472	S	N	20
29	B	0	0	1	3490	1.30	-2000	S	Y	201
29	C	0	0	1	3490	1.00	-2500	G	Y	201

NOTE:

SEE FIGURE 1 FOR POTHOLE LOCATION CODES.

(1) THE NEGATIVE SYMBOL INDICATES THAT THE ACTUAL POTHOLE DRYFLOW IS SOMEWHERE BELOW THE VALUE SHOWN.

(2) -0- IN SUBSTRATE OR COVER COLUMN INDICATES NO DATA.

(3) SOURCE CODE IS A CODE THAT DESCRIBES THE SOURCE OF EACH POTHOLE CONNECTION AND DRY FLOW ESTIMATE.

SOURCE CODE:

INSAMPLE/RANDOM POTHOLES : 1 $
ALL OTHER POTHOLES : 2 $
DRYFLOW/CONNECT FLOW : $ 0
ESTIMATES (DERIVED USING METHODS ILLUSTRATED BY FIGURES 2 AND 3)
DRYFLOW BY REGRESSION : $ 1
CONNECT FLOW FROM JONES AND STOKES, INC. : $ 2
DRYFLOW FROM JONES AND STOKES, INC. : $ 3
$ 1 $ AND $ 2 $: $ 4
$ 2 $ AND $ 3 $: $ 5
ROUGH ESTIMATE OF DRYFLOW : $ $ 1
(FROM DATA OBSERVATION)

SUBSTRATE CODE:

S = SAND
G = GRAVEL
C = COBBLE
M = MUD

potholes in this study reach stranded fry, with the average number stranded per pothole ranging up to 1.75 fry.

Pothole cover and substrate characteristics were also field documented. Potholes in the middle study reach were associated with cover more often than in the lower reach, 75% versus 50% respectively. Substrate also appears to change by reach, as might be expected given the differences in stream gradient between reaches. The lower reach potholes were dominated by small substrate and the middle reach potholes were dominated by larger substrate.

TABLE 11

POTHOLE SUMMARY DATA FOR TWO STUDY REACHES SHOWING THE DISTRIBUTION, AND NUMBER OF POTHOLES THAT TRAPPED AND STRANDED FRY, RANGE OF NUMBERS TRAPPED AND STRANDED, PERCENT OF POTHOLES WITH/WITHOUT COVER, AND POTHOLE SUBSTRATE TYPE

River Location	Total Potholes	Potholes Trapping	Potholes Stranding	Range of #'s Trapped	Range of #'s Stranded	% With Cover	Substrate Type (% of pH's) C	G	S
Lower Reach	188	77	28	0-128	0-14	50	16	36	48
Middle Reach	44	13	3	0-137	0-1.75	41	28	31	

A total of 890 observations were made of potholes that had become disconnected as a result of the downramp amplitude testing parameter. All of these observations represent a pothole that had the opportunity to trap and/or strand fry. Figure 6 is a flow chart that summarizes pothole trapping and stranding characteristics using these 890 observations.

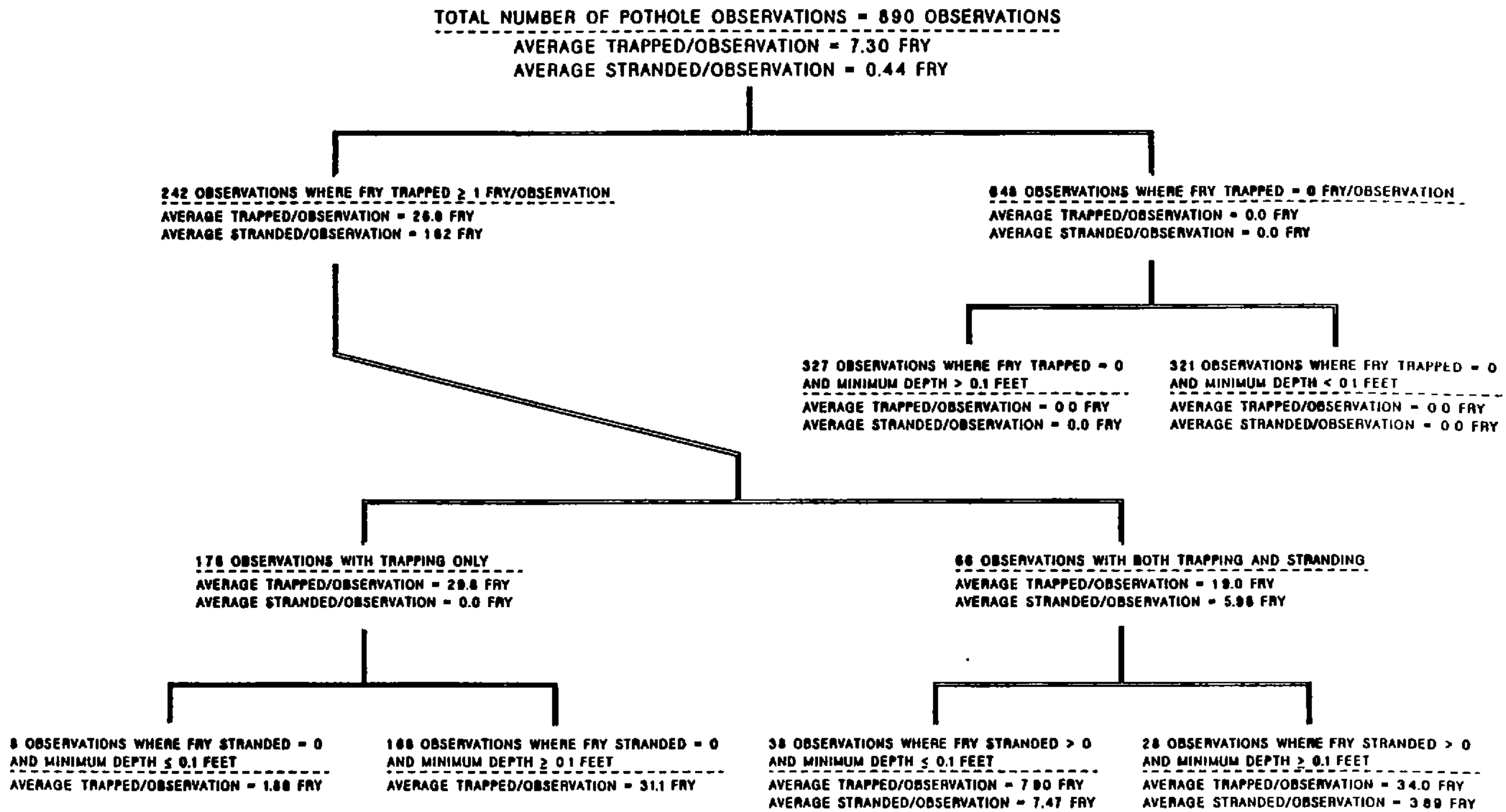
Starting at the top of the flow chart are the 890 pothole field observations. These observations represent potholes that trapped and/or stranded fry and others that did not. They trapped on the average 7.3 fry and stranded 0.44 fry. The flow chart then branches out to observations that either trapped or did not trap fry. Most (648 of 890) of the observations had not trapped or stranded fry, and 242 of the observations had trapped or stranded fry averaging 26.8 and 1.62 respectively.

Of the 242 observations trapping or stranding fry 176 observations trapped fry and did not strand, averaging 29.8 fry/observation. Of these, only 8 of the observations when pothole minimum depths were less than 0.1 foot trapped fry averaging only 1.88 fry. The other 168 observations with pothole minimum depths greater than 0.1 foot averaged 31.1 fry.

The other 66 observations trapped and stranded fry, averaging 19.0 trapped and 5.96 stranded. Of these 66 observations, 38 trapped an average of 7.9 fry

FIGURE 6

SUMMARY DIAGRAM OF POTHOLE TYPES AND CHARACTERISTICS BASED ON 890 FIELD OBSERVATIONS



and stranded an average 7.47 fry when the minimum pothole depth was less than 0.1 foot. The remaining 28 observations trapped an average of 34.0 fry while stranding 3.89 fry when pothole depths exceeded 0.1 feet.

The flow chart clearly indicates that many potholes do not trap or strand fry. Many of those that do can also be characterized as potholes that merely trap fry, especially those that generally maintain at least a minimal water depth. A very small percentage of all potholes actually stranded fry of which there are two types; potholes that stranded the highest number of fry also had the lowest trapping total which can be interpreted as meaning that these potholes do not trap large numbers of fry but those they trap are usually stranded and, secondly, potholes that on the average trapped large numbers of fry but stranded relatively few of them because they rarely went completely dry.

2. POTHOLE CONNECTION AND DRY FLOW DETERMINATIONS

A total of 232 potholes were assigned connection flows using the different methods discussed in Section III. Table 10 shows the connection flows for each of these potholes and the method used to compute them. The connection flow distribution for potholes that trapped fry is shown in Figure 7. Approximately 50% of these potholes had connection flows between 4,000 and 5,000 cfs as measured at the Marblemount gage.

Table 10 also lists the calculated dry flows for individual potholes using the methods described in Section III. The distribution of pothole dry flows is shown in Figure 7. The dry flows had a normal distribution that ranged from 1,000 to 5,500 cfs, with a peak in the distribution at 3,000 to 4,500 cfs as measured at Marblemount.

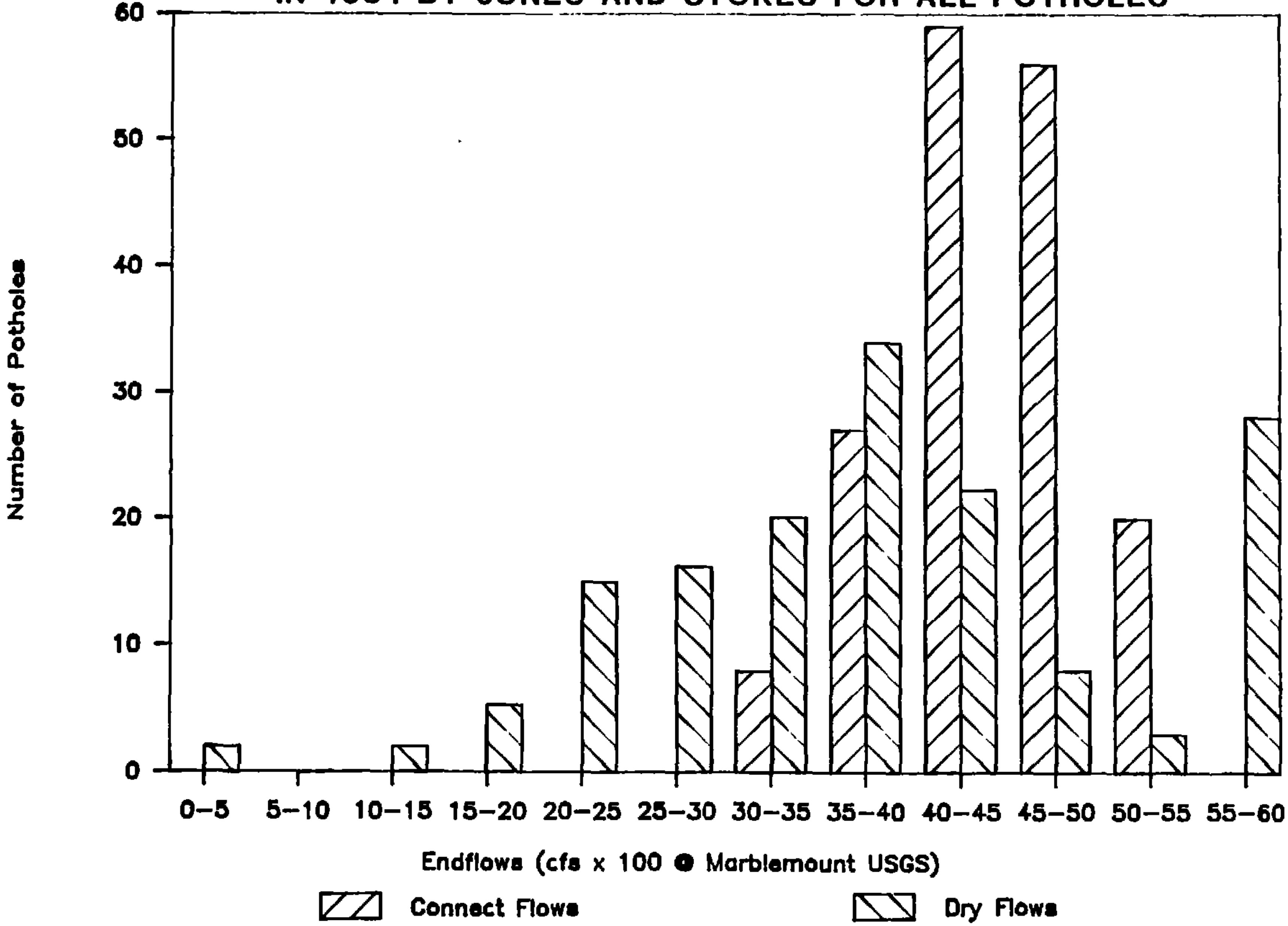
3. PHYSICAL AND HYDROLOGIC FACTORS AFFECTING POTHOLE TRAPPING AND STRANDING

The pothole stranding process is composed of two principal stages: trapping which is defined as the capture of fry in a pool isolated from the main-channel flow; and mortality due to stranding usually caused by the dewatering of a pothole. The trapping stage has two main subcomponents. The first is strictly a function of downramping hydrologic factors which consists of the physical formation of a pool of water in a depression on the bar which is fully separated from main-channel flow. The second subcomponent is the capture of fry in these water-filled depressions which is affected by the presence, and the behavior of fry. It is assumed that the presence of fry is subject to systematic and predictable seasonal variations and short-term (hourly/daily) largely unpredictable fluctuations. The systematic variations in population densities were accounted for in this study through a temporally balanced experimental design.

The database used in these analyses consisted of 890 records (see Figure 6), each of which represents one (1) disconnected pothole and one (1) test date. The USGS flow data used to assign pothole connection flows is accurate to approximately 500 cfs (personal communication, USGS). Therefore, only pothole observations where the beginning flow was within 500 cfs of the

FIGURE 7

FREQUENCY DISTRIBUTION OF POTHOLE DISCONNECTION AND DRY FLOW FROM DATA COLLECTION IN 1985 BY R.W. BECK AND ASSOCIATES AND IN 1984 BY JONES AND STOKES FOR ALL POTHOLES



estimated connection flow for individual potholes were included in this database. The original study design was not completed as a result of weather and uncontrollable tributary inflows. The test dates and flow conditions resulting from the incomplete experimental design caused confounding of time and flow parameters.

A total of 15 tests were completed without complications. However, the last two tests (May 19-20) did not have USGS hydrologic data due to failure of their gage stations. The data for these two test dates were used in other parts of the analysis where hydrologic data were not needed. Certain parts of the analysis did require hydrologic data which reduced the number of successful test days to thirteen (13). Field data were collected from 23 pothole areas and 232 individual potholes. Fifty-five (55) of these potholes had more than seven observations and 31 of these had more than 10 observations. In most cases the number of observations were controlled by the connection flow of the pothole and the beginning and endflow of the downramping event. If a pothole was not connected prior to a test it was not considered an observation even though data may have been collected.

a. Factors Affecting Pothole Trapping

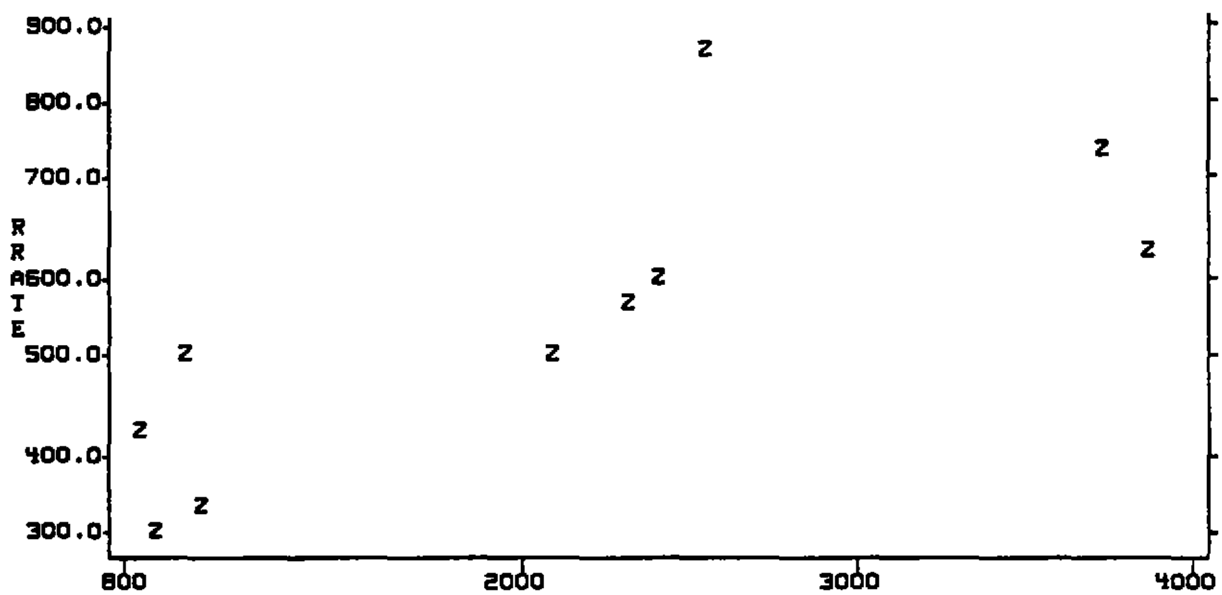
Among the hydrological factors hypothesized to affect the "trapping efficiency" of any given pothole are ramping rate, downramp endtime (day/ night), and flow history.

The ramp rates used during the study were scheduled to vary between 1,000 and 2,000 cfs per hour at Newhalem. The resulting ramp rates as measured at the Marblemount stream gage were significantly reduced in range and magnitude as a result of distance. These ramp rates blended together rather than segregating into two distinguishable groups. These rates were reduced further downstream where most of the potholes and observations were made. In fact, ramp rate became obscured as measured at Marblemount. Ramp rate also appears confounded with amplitude (See Figure 8). Confounding is also apparent between ramp rate and beginning flow (Figure 9).

Figures 10-12 display the relationship between ramp rate and fry trapping within each of three levels of beginning flow. Note the narrow range of observed ramp rates and the lack of correlation between trapping and ramp rate. Tributary inflows obscured the range of ramp rates even more, virtually eliminating any opportunity to examine ramp rate effects on fry trapping. Since results presented in this report and field experience suggest that fry trapping depends more upon pothole fry recruitment than escape opportunities, the notion of ramp rate as a measure of how fast the trap closes does not appear to be of importance. Any role it might play in affecting pothole recruitment conditions could not be assessed due to the narrow range of ramp rate observations.

The downramping endtimes of each of the 13 tests varied depending on the test type and the operational constraints brought upon by power generation needs. Individual test endtimes were compared with their corresponding average trapped/pothole involved in the test. This comparison, like ramp rate, did not show any significant effect when other factors such as beginning flow were accounted for. Two levels of end time were observed at a single beginning flow level (4,670 cfs beginning flow). A Kruskal-Wallis test yielded a P-value of

Figure 8 - Ramp Rate Versus Amplitude (1985 Pothole Study)



Statistics for RRATE and AMP.

	RRATE	AMP
Mean:	593.954	2519.103
Standard deviation:	141.647	1095.035
Minimum:	303.333	860.000
Maximum:	848.000	3821.000
N:	890	

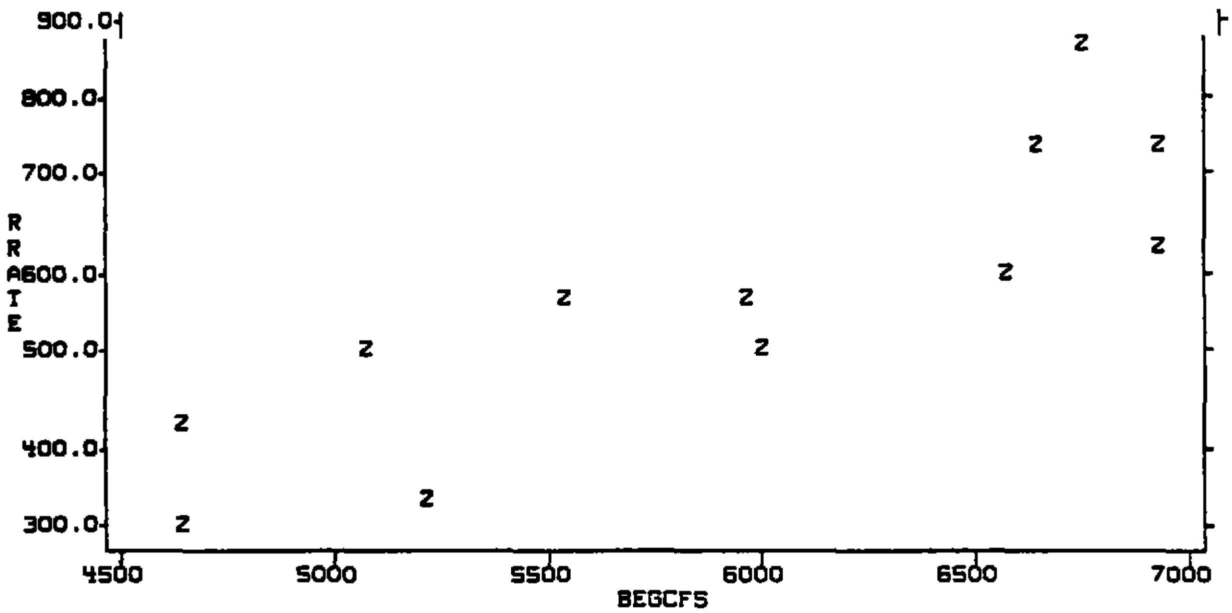
note: letters in relationship represent multiple observations (*=1, B=2, C=3, and Z=>26)

Number of observations with one or both variables missing: 0

Correlation and two-tailed P-value: 0.7774 [P<0.0000]

Regression line for predicting RRATE from AMP: RRATE = 340.6397 + .1005574 * AMP

Figure 9 - Ramp Rate Versus Beginning Flow - (1985 Pothole Study)



Statistics for RRATE and BEGCFS.

note: letters in relationship represent multiple observations ($=1, B=2, C=3, and Z=>26)

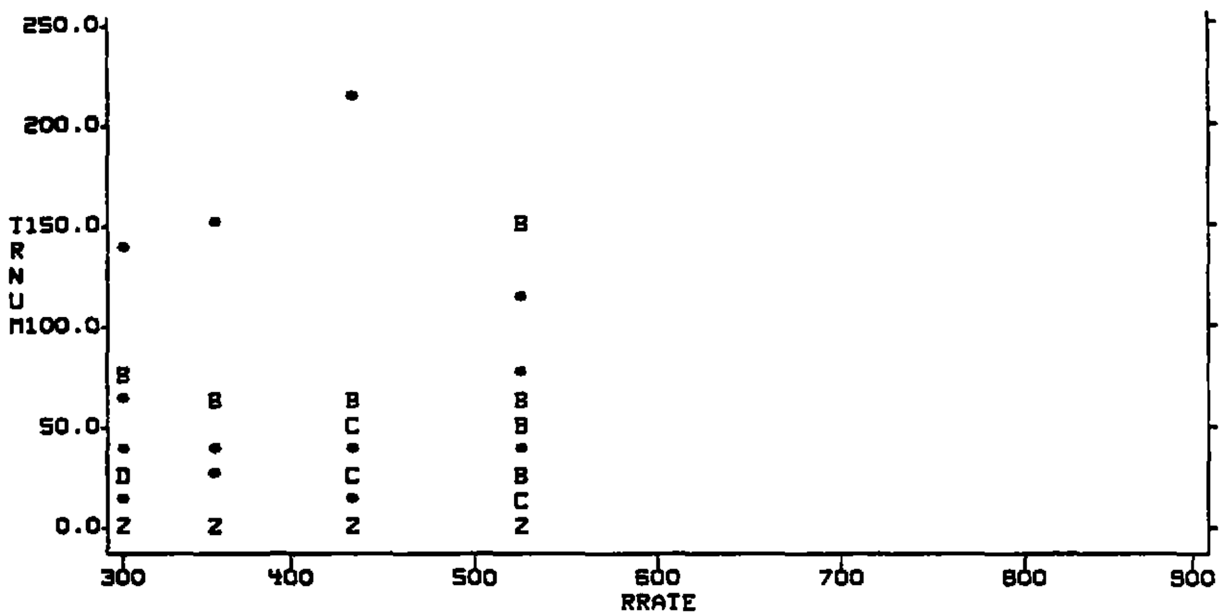
	RRATE	BEGCFS
Mean:	593.954	6105.466
Standard deviation:	141.647	780.376
Minimum:	303.333	4670.000
Maximum:	848.000	6895.000
N:	890	

Number of observations with one or both variables missing: 0

Correlation and two-tailed P-value: 0.8372 [P<0.0000]

Regression line for predicting RRATE from BEGCFS: RRATE =-333.7863 + .1519524 * BEGCFS

Figure 10 - Pothole Trapping Versus Ramp Rate For Beginning Flows Less Than 5,500 cfs



1 points are outside the limits of the plot.

Statistics for TRNUM and RRATE.

note: letters in relationship represent multiple observations (*=1, B=2, C=3, and Z=>26)

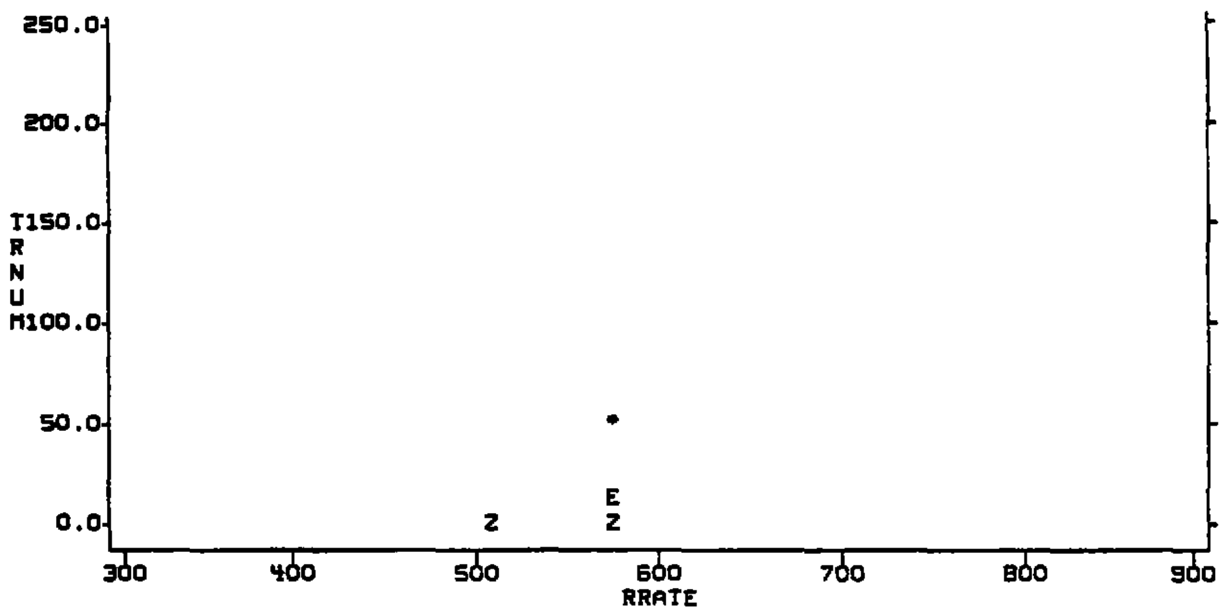
	TRNUM	RRATE
Mean:	15.681	414.732
Standard deviation:	71.939	89.807
Minimum:	0.000	303.333
Maximum:	1000.000	526.000
N:	226	

Number of observations with one or both variables missing: 0

Correlation and two-tailed P-value: -0.0509 [P<0.4462]

Regression line for predicting TRNUM from RRATE: TRNUM = 32.59615 +-4.078479E-02 * RRATE

Figure 11 - Pothole Trapping Versus Ramp Rate For Beginning Flows Betwe
5,500 and 6,500 cfs



Statistics for TRNUM and RRATE.

note: letters in relationship represent multiple observations (*=1, B=2, C=3, and Z=>26)

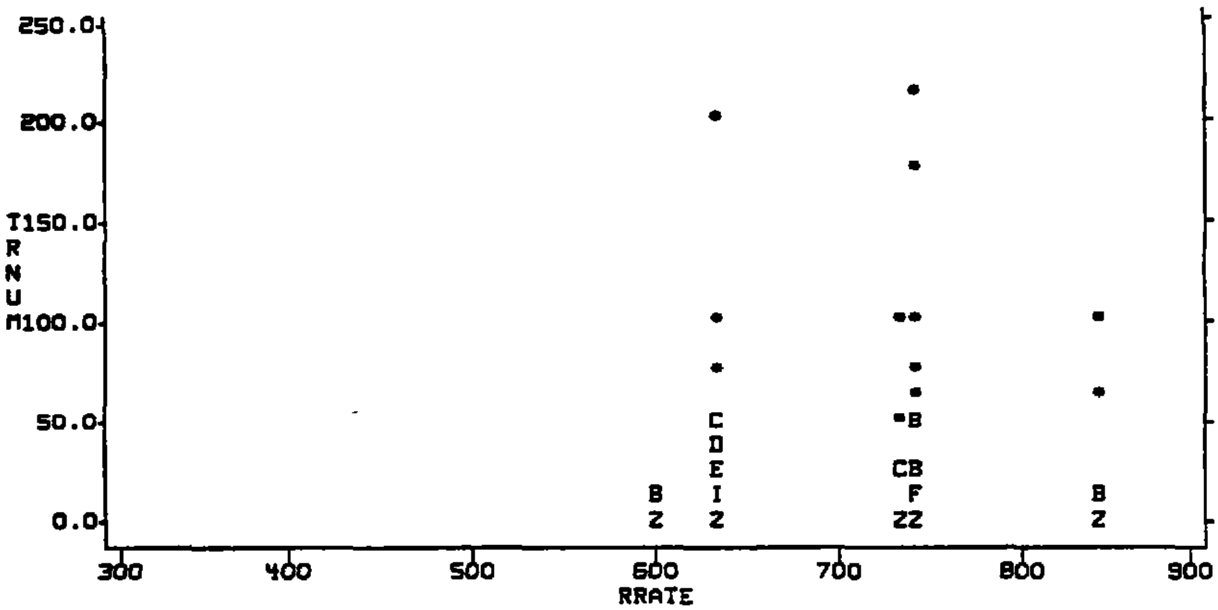
	TRNUM	RRATE
Mean:	0.966	552.401
Standard deviation:	4.657	34.194
Minimum:	0.000	507.500
Maximum:	52.000	578.750
N:	205	

Number of observations with one or both variables missing: 0

Correlation and two-tailed P-value: 0.1375 [P<0.0493]

Regression line for predicting TRNUM from RRATE: TRNUM =-9.377317 + 1.872402E-02 * RRATE

Figure 12 - Pothole Trapping Versus Ramp Rate For Beginning Flows Greate Than 6,500 cfs



Statistics for TRNUM and RRATE.

	TRNUM	RRATE
Mean:	5.993	700.753
Standard deviation:	20.958	80.053
Minimum:	0.000	599.250
Maximum:	210.000	848.000
N:	459	

note: letters in relationship represent multiple observations (*=1, B=2, C=3, and Z=>26)

Number of observations with one or both variables missing: 0

Correlation and two-tailed P-value: 0.0108 [P<0.8173]

Regression line for predicting TRNUM from RRATE: TRNUM = 4.009802 + 2.830759E-03 * RRATE

0.35 indicating no significant effect due to end time in this stratum of constant beginning flow. The opportunities to test for day-night differences were limited due to partial confounding with beginning flow. If there is an effect due to day-night downramping end times, it could not be detected using our incomplete database.

Flow history, hours of stable flow prior to a downramp, was thought to have some influence on fry trapping. The flow history factor is directly related to fry behavioral patterns. For example, if the river stage is held constant for 1 hour, 8 hours, or 1 day or longer prior to a downramp, will this have an effect on fry trapping? It has been suggested that fry may behave differently, depending on what hydrologically occurs prior to a downramp. In this study the flow history factor measures the status of the habitat in the vicinity of the pothole for some period preceding the flow reduction. One of the objectives of the experimental design was to create flow history patterns which might be analyzed to determine if, for example, consecutive downramping events are independent of one another. The premature termination of the study prevented such analysis. However, a body of studies and experience accumulated by Troutt (1985), Ladley (1986), and field observations by Pflug during this study suggest that trapping occurs when the waterline recedes due to reductions in streamflow, but that several other factors may control how many fry will become trapped. Some of these factors relate to flow history in a different or more specific context than how this study first defined flow history (hours of stable flow prior to a downramp).

Troutt and Pauley (1985) studied the residency time of various fry species once they enter a pothole. They found that some chinook fry remain in potholes for longer than one full downramp-to-downramp cycle. This indicates that some chinook fry may remain in potholes for more than one cycle while others may move out of a pothole during an upramp and back into the same pothole again during the next downramp event. The factors controlling a fry's decision to remain in a pothole that has reconnected to the main channel is very likely the depth of pothole overflow and the water velocity. The deeper the water flowing over the pothole following reconnection, the less attractive the pothole may become to fry that prefer slower velocities and cover. Conversely, if pothole overflow is minor (approximately 3 inches), fry already in a pothole may elect to remain since pothole conditions may not have changed much from those first encountered. The results of this theorization is that the flow history (number of hours of stable flow prior to a downramp) is probably of little importance compared with river stage (controls pothole overflow level) prior to a downramp in terms of influencing fry trapping.

One aspect of flow history that is of great importance is the status of individual potholes at the time a downramp begins. The parameter that most accurately represents this status is derived from the difference between the flow at the beginning of the downramp event (beginning flow) and the flow at which each pothole becomes disconnected from the main-river channel (connection flow). This difference, the "overflow" parameter, is a relative measure of the degree to which a pothole is submerged at the beginning of a downramp. A pothole with a 3,000 cfs connection flow would have a greater overflow depth with a 6,000 than a 4,000 cfs downramp beginning flow.

Pflug (1985-86) completed many hours of field observation combined with electroshocking of various habitat types. He suggests, based upon his observations, that fry demonstrate a definite preference for waters-edge habitat. During upramp events, these fry constantly adjust to changes in the waterline as it moves up the streambank. Several times he observed small groups of fry move into a pothole as it became connected during an upramp event. These same fry when chased out of the pothole into the main channel, often returned within only a few minutes time. Further observation revealed that as the waterline continued to move up the streambank these fry moved also, leaving the pothole which by then was indistinguishable from main channel flow.

Ladley (1986) studied recruitment of fry into potholes that connect daily to main channel flow. His results indicate that pothole recruitment rate was strongly influenced by downramp beginning flow and the beginning flow history (beginning flows of downramps preceding a pothole sampling date). When beginning flows were repeatedly near the connection flows of his study potholes, fry recruitment into these potholes incrementally increased. However, when a high beginning flow followed a series of low beginning flows the fry recruitment did not increase. The speculation was that a high beginning flow effectively flushed fry out of potholes due to large pothole overflows and current velocities. Conversely, when low beginning flows were repeated over and over again fry could remain in the potholes between downramps and other fry from the main channel could locate and recruit into these potholes. Then, at some point, a higher beginning flow occurs and these fry are flushed from the pothole starting the process of pothole recruitment over again. Further detail is given in Section VI.

The relationship between the average-fry-trapped (average number of fry trapped in pothole), and pothole overflow to beginning flow is shown by Figure 13. This graph demonstrates that as beginning flow increases from approximately 4,500 to 5,500 cfs, indicated as Zone 1 on the graph, the average-fry-trapped decreases from the highest average trapping value to the beginning of a series of very low average trapping values. Zone 1 is also where the overflow values are lowest, meaning that the beginning flows in this zone are very close to the connection flows of potholes. Hence, there is less water covering potholes which suggests that potholes are closer to the waters-edge. Waters-edge habitat is where most of the fry are located.

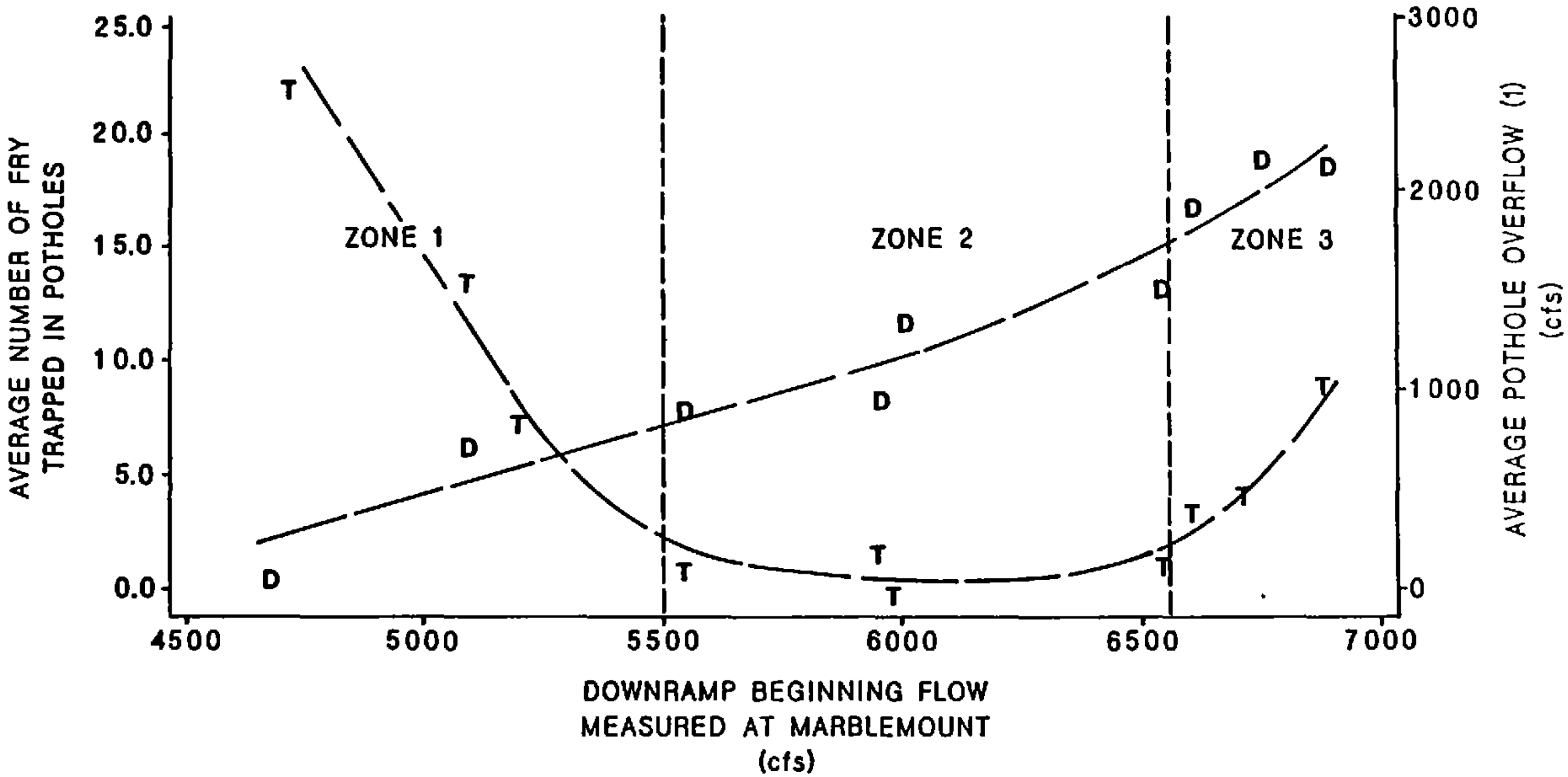
In Zone 2, the average-fry-trapped values are consistently the lowest found in the relationship and they are bounded by beginning flows of 5,500 and 6,500 cfs. The overflow values continue to increase in Zone 2 which is expected since an increase in river stage will increase the depth of water over a given pothole. Since all observations were of potholes with connection flows less than 6,000 cfs, these potholes will be further away from waters-edge habitat as the beginning flow waterline moves up the streambank.

In Zone 3 the average-fry-trapped values began to increase again and did so consistently up to the highest beginning flow tested. This occurred as the overflow values continued to increase and waters-edge consequently moved further away from the pothole.

Within the range of tested and observed beginning flows, fry trapping was highest when the overflow was lowest and then decreased as overflow increased

FIGURE 13

RELATIONSHIP BETWEEN DOWNRAMP BEGINNING FLOW AND THE AVERAGE NUMBER OF FRY TRAPPED IN POTHOLES AND AVERAGE POTHOLE OVERFLOW (WHICH IS DOWNRAMP BEGINNING FLOW - POTHOLE CONNECTION FLOW)



D - AVERAGE POTHOLE OVERFLOW

T - AVERAGE TRAPPED PER POTHOLE

(1). This value is the average of all the differences of Downramp Beginning Flow and Individual Pothole Connection Flows in cfs. The smaller this value the smaller the water depth covering the pothole.

and then unexpectedly began to increase with overflow (Figure 13).

The relationship between average-fry-trapped and beginning flow was closely examined to determine if factors other than overflow might explain the observed trends. Specifically, downramp ending time could be ruled out as a potential cause of this effect. For example, observations were made at six (6) different levels of Marblemount downramp beginning flow (4,670 - 6,895 cfs) with a 3 a.m. Marblemount downramp end time. An additional set of observations were made at three (3) different levels of beginning flow (5,540 - 6,615) with a 4 a.m. downramp end time. Both of these independent data sets show a relationship between pothole trapping and beginning flow which is consistent with our earlier relationship, which includes observations of all downramp end times (Figures 14 and 15). Furthermore, a Kruskal-Wallis non-parametric test confirms the significance of beginning flow for each level of end time (Figures 14 and 15). Consequently, two independent data sets reconfirm the relationship between downramping beginning flow and pothole trapping shown in Figure 13. The upward tendency of trapping in Zone 3 is somewhat unexpected. The behavioral response and hydrology reflected here require further analysis. More insight into this phenomenon might be gleaned from further examination of our data. Such analysis was beyond the scope of the current study.

b. Factors Affecting Pothole Stranding

Pothole stranding takes place after fry have been trapped in a pothole. Most pothole related mortality occurs when potholes containing fry go dry and each pothole has its own dry flow. The number of fry stranded in a pothole is a function of pothole drainage characteristics, river flow, and the number of fry trapped. Once trapped in a pothole, fry cannot escape and stranding is determined by downramp endflow and pothole dry flow. For all practical purposes the only physical or hydrologic factors that affect fry stranding are the dry flows of potholes that trap fry and the downramp endflow level and duration.

Two other factors may also contribute to the death of fry trapped in potholes. Fry can fall prey to predators (raccoons, blue herons) while trapped in potholes and elevated water temperatures could also be lethal if critical temperatures are reached. The contribution to total pothole mortality of these two factors would be extremely difficult to quantify let alone speculate on.

During the two springs of field studies water temperatures did not approach critical levels and predation on fry trapped in potholes was never verified although it is likely that both sources of potential mortality do occur.

4. POTHOLE TRAPPING AND STRANDING SIGNIFICANCE

Another objective of the spring 1985 pothole study was to provide a means for determining the relative magnitude of salmon fry trapping and stranding in potholes within the Skagit River study area. Earlier research did not provide a means for predicting the relative magnitude of the pothole stranding problem. The impact of pothole dewatering is best measured by the number of fry stranded, not by the number trapped, for a given set of Gorge Powerhouse operations criteria such as ramp rate and beginning and endflow of a downramp event. The number of trapped fry is less significant since they are not usually harmed in

FIGURE 14

SIX LEVELS OF BEGINNING FLOW VERSUS AVERAGE TRAPPED AT DOWNRAMP ENDTIME OF 3-AM

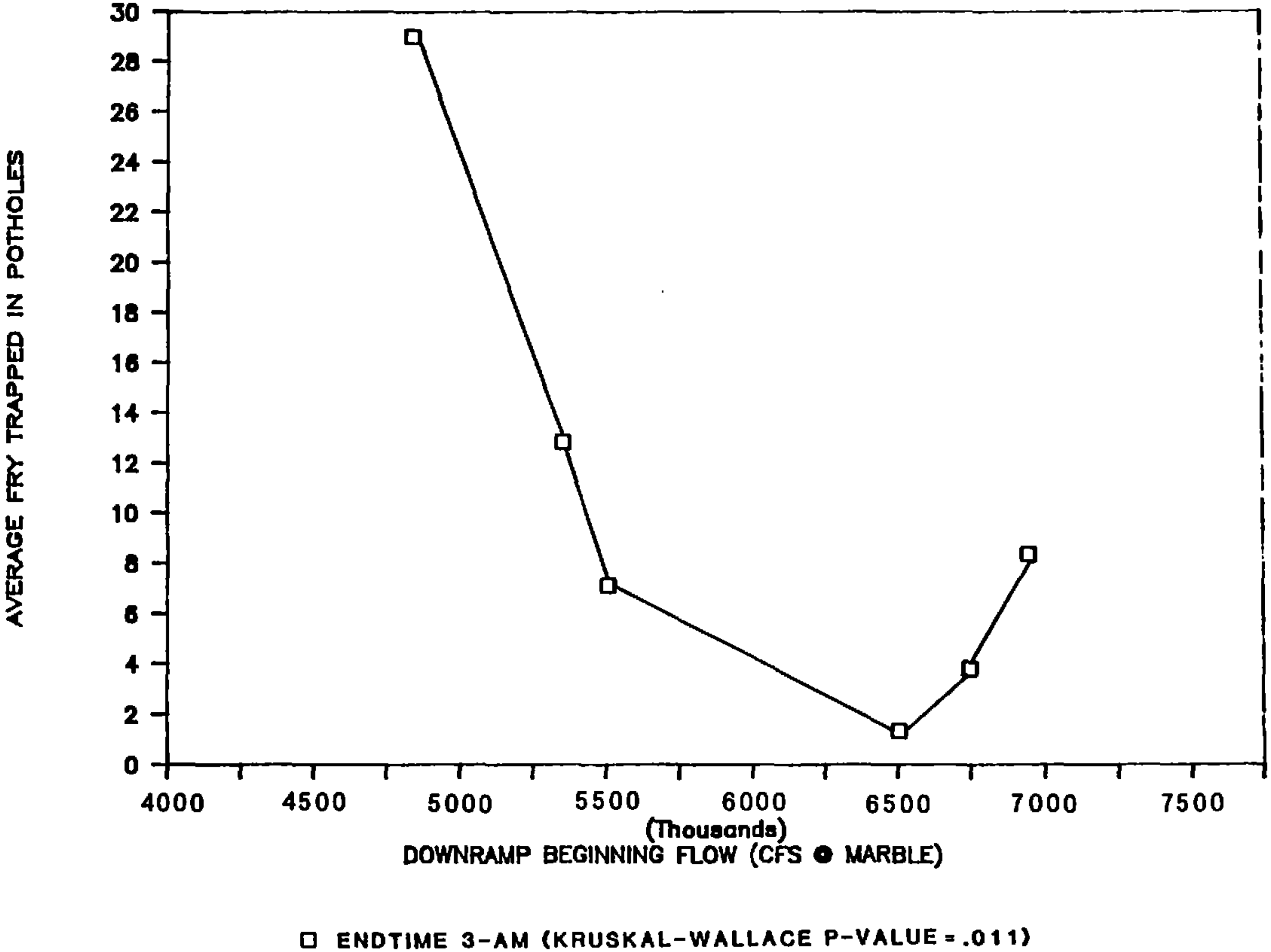
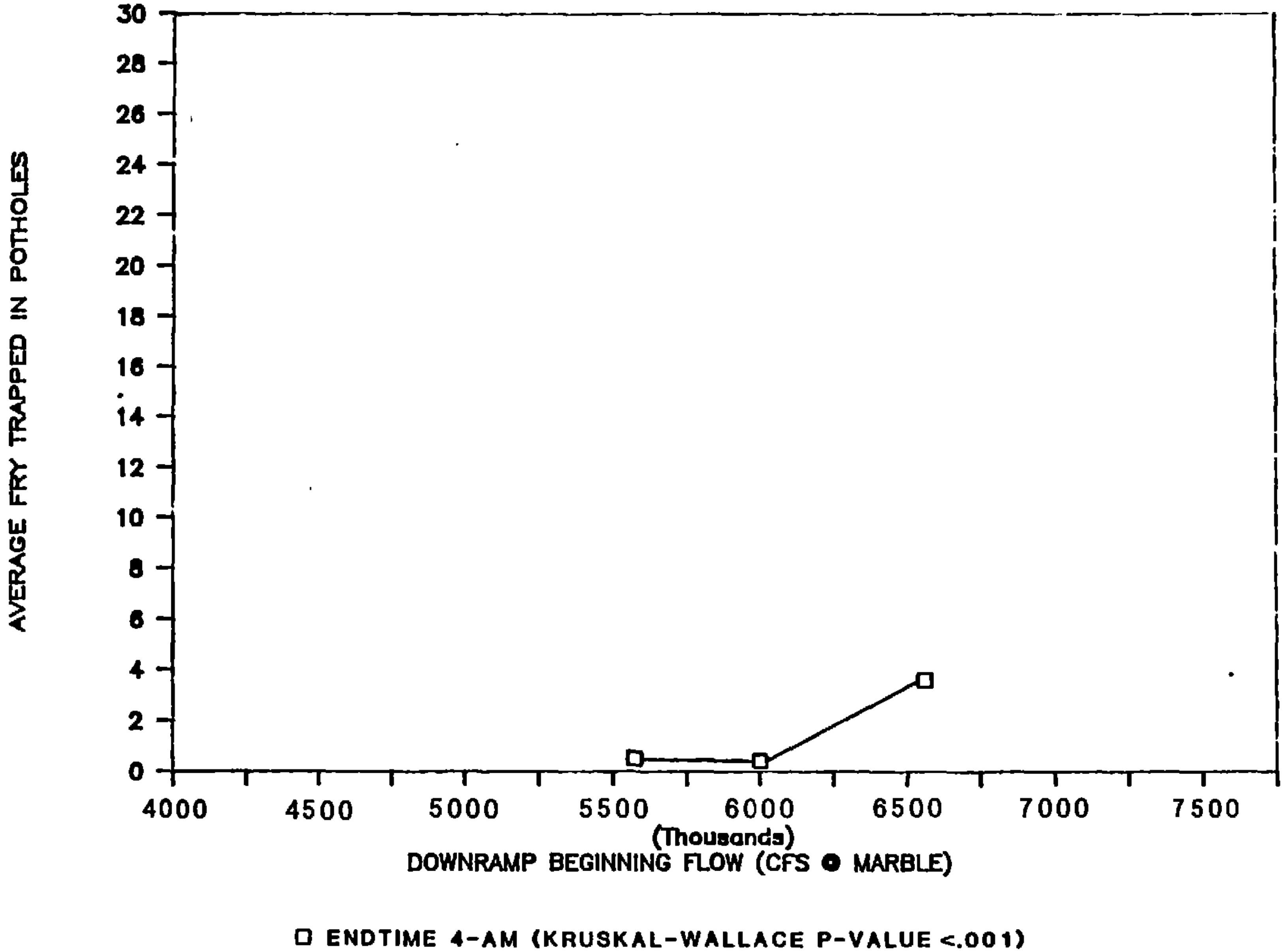


FIGURE 15

THREE LEVELS OF BEGINNING FLOW VERSUS AVERAGE TRAPPED AT DOWNRAMP ENDTIME OF 4-AM



any way. It should be mentioned here that depending on the physical characteristics of a pothole, trapped fry are subject to predation and elevated water temperature which are two other possible sources of mortality. Although these sources of mortality are present their importance and magnitude are difficult to quantify, let alone speculate on. This study was designed so that a matrix could be produced that is capable of estimating, within the limits of the study, the number of potholes that become disconnected and the average number fry trapped and stranded for six combinations of amplitude fluctuations and ramping rates. The matrix does not account for potholes located in the unstudied upper reach (Bacon Creek upstream to Gorge Powerhouse) or for other sources of error such as observer error and predation on fry trapped and stranded in potholes.

The matrix shown in Figure 16 estimates through linear modeling the number of potholes that become disconnected, the average number of fry trapped, and stranding results from 21 specified downramp events. The statistical level of confidence in these predictions is unknown. The potholes used in this analysis were those studied during the spring 1985 study, which incorporated all potholes from the Jones and Stokes, Inc. 1984 Pothole Stranding Study and others identified by R. W. Beck and Associates during our work. The bounds of the matrix are limited to the range of flows specified by the study design. The matrix could be expanded beyond these bounds if pothole trapping and stranding tests were conducted in the range of flows above and below those studied. The matrix can be used by selecting a downramp beginning flow between 3,500 - 6,000 cfs and a downramp endflow from 5,500 - 3,000 cfs and reading the data within the corresponding matrix cell. Each cell contains the number of potholes that would have started the downramp connected to the main-channel flow and finished the downramp disconnected and perhaps dry, the average number of fry trapped in these potholes, and the average number of fry that would be stranded. For example, a downramp with a 5,500 cfs begin flow and a 3,000 cfs endflow would create 168 disconnected potholes, with 1,188 fry trapped and 75.6 stranded. The matrix shows that as amplitude fluctuation increases, so does the number of fry trapped and stranded.

The matrix data can be applied to the daily operational flows at Gorge Powerhouse during the vulnerability period, conservatively February-May, to derive an estimate of the total number of salmon fry stranded in potholes. A "high side" calculation case scenario of 76.5 fry per downramp event (begin flow of 6,000 cfs with an endflow of 3,000 cfs) over the 120 day vulnerability period would produce a season-long estimate of 9,180 salmon fry stranded from Rockport to Bacon Creek. Within the limits of this study this number overestimates the total fry stranded, since actual power generation patterns do not resemble the downramp event levels used to produce this season-long estimate. Above Bacon Creek, potholes are less common, but present. But, trapping and stranding was not formally monitored so pothole stranding predictions can not be made for the reach between Bacon Creek and Newhalem. The example of the season-long prediction does not reflect the actual operational patterns used by Seattle City Light. A more realistic prediction could be derived from USGS flow records for the Marblemount gage used in conjunction with the Newhalem gage flow records.

This estimate needs further qualification since it does not and could not account for several sources of error beyond those mentioned above such as observer error and predation on fish trapped or stranded in potholes. This estimate does not attempt to represent an absolute stranding total, but does

FIGURE 16

PREDICTED NUMBER OF POTHOLES DISCONNECTED, AVERAGE NUMBER OF SALMON FRY TRAPPED AND STRANDED RESULTING FROM A SPECIFIED DOWNRAMP EVENT

END FLOW (1) →

BEGIN FLOW (2) ↓

RANGE OF OBSERVED END FLOWS DURING THE 1985 STUDY SEASON

RANGE OF OBSERVED BEGIN FLOWS DURING 1985 STUDY SEASON

Begin flow \ End flow	3000	3500	4000	4500	5000	5500
3500	P=7 T=137.1 S=4.4					
4000	P=34 T=342.0 S=26.0	P=27 T=204.9 S=21.6				
4500	P=93 T=669.4 S=39.3	P=86 T=532.3 S=34.9	P=59 T=327.4 S=13.3			
5000	P=148 T=903.6 S=72.5	P=141 T=766.5 S=68.1	P=114 T=561.6 S=46.5	P=55 T=234.2 S=33.2		
5500	P=188 T=1187.6 S=75.6	P=161 T=1050.7 S=71.2	P=134 T=845.8 S=49.6	P=75 T=516.4 S=36.3	P=20 T=284.2 S=3.1	
6000	P=226 T=1377.4 S=76.5	P=221 T=1200.3 S=72.1	P=192 T=995.4 S=50.5	P=133 T=668.0 S=37.2	P=78 T=433.8 S=4.0	P=58 T=149.6 S=0.9

TYPICAL CELL ENTRY

P = Number of potholes that become disconnected in the designated begin-to-ending flow range of a downramp event.

T = Summation of the average fry trapped in potholes disconnected in the downramp event

S = Summation of the average strand for each pothole disconnected in the downramp event.

(1). Flows measured at Marblemount USGS Gage at the end of a downramp event.

(2). Flows measured at Marblemount USGS Gage at the start of a downramp event.

provide an index of the relative magnitude of the problem given the limits of the study and unaccounted for sources of error.

5. POTHOLE RESIDENCY TIMING FOR SALMON AND STEELHEAD FRY

This study task was designed specifically to evaluate the residency time of salmonid fry in potholes. A more detailed version of the study report can be found in Appendix E.

It should be noted here that a quantitative analysis was not possible and, as such, only simple summary statistics such as the number of observations, means, standard deviations, and confidence intervals could be produced for the results (See Appendix E). Appendix E also addresses a potential sampling weakness which may have produced a significant bias in the residency time results.

With this in mind, it is important that the results be used very carefully due to their qualitative nature. It does appear that most fry species are remaining or returning to particular potholes for more than one downramping event, even when given the opportunity to escape from the pothole.

a. Species Stranded, Fish Length, and Residence Time

Most of the fry trapped in potholes in the spring were chinook salmon, with lesser numbers of coho and chum salmon (Figure 17). The percentage of chum salmon increased as the spring study progressed (Figure 17). During the summer large numbers of steelhead and coho salmon fry were trapped in potholes (Figure 17). The dominance of chinook salmon in the spring, and steelhead and coho salmon in late summer, was expected because salmon and steelhead fry trapping in potholes reflects habitat preferences and the relative abundance of each fry species.

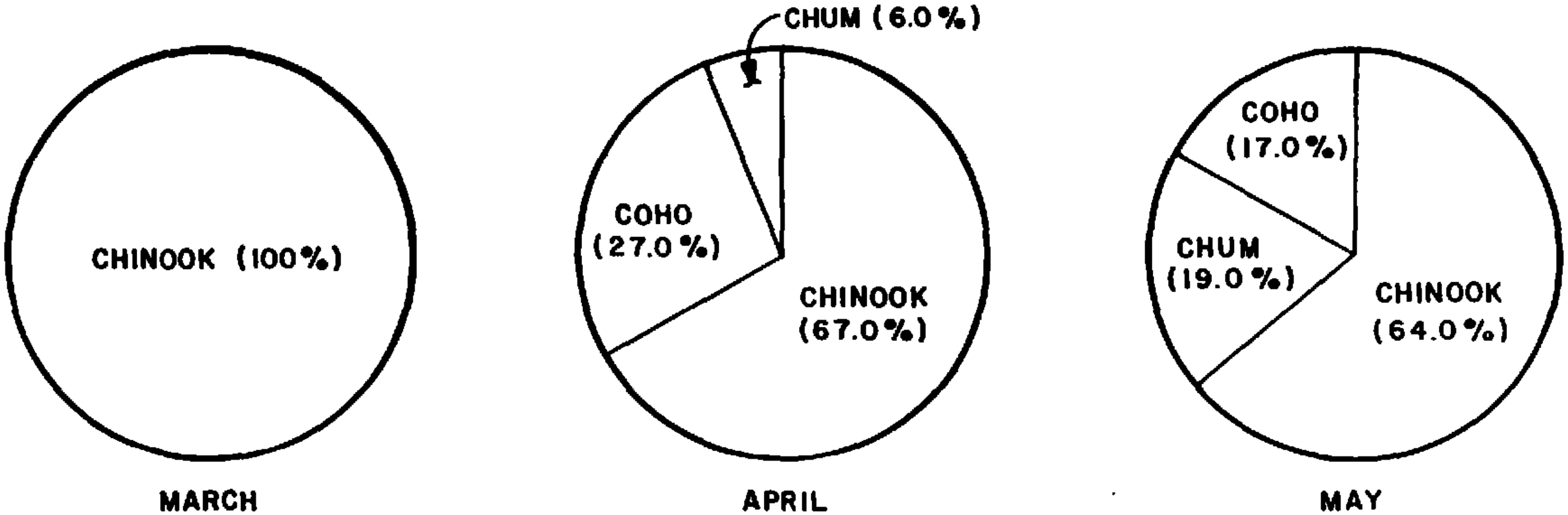
Chinook salmon fry trapped in potholes averaged 40 mm in total length during March with the average size gradually increasing to 45 mm by May. Chinook fry up to 48 mm were commonly trapped but only one chinook over 50 mm was collected from a pothole.

Due to the presence of two-year classes, coho trapped in potholes were more variable in length than chinook. Yearling coho salmon up to 80 mm in length were trapped in the spring, although the average size was only 38 to 41 mm. Newly emerged chum salmon trapped in potholes averaged 40 to 42 mm in length. For all species, the overwhelming majority of trapped fish were young-of-the-year that had recently emerged from redds.

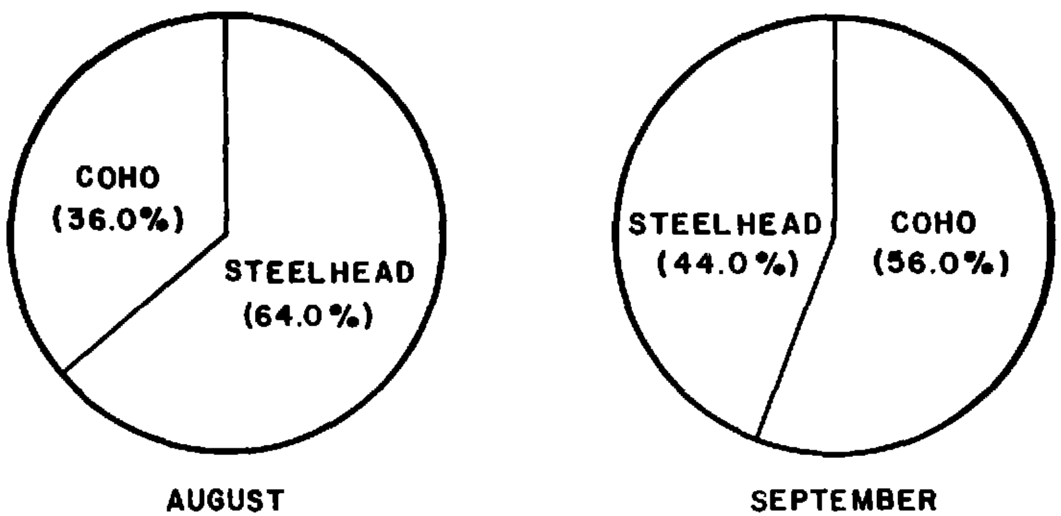
FIGURE 17

MONTHLY CHANGE IN FRY SPECIES COMPOSITION FOR SPRING AND SUMMER STUDY PERIODS. (TROUTT AND PAULEY, 1985)

SPRING POTHOLE STUDY



SUMMER POTHOLE STUDY



Troutt and Pauley, 1985, estimate that chinook salmon fry spent an average of 2.4 days in potholes during the spring, and their residency time appeared to decrease slightly as the study progressed (Figure 18). Coho salmon fry averaged 1.4 days in potholes during the spring study and 1.4 days during the summer study. Residence time of coho salmon fry decreased from August to September (Figure 18). Chum salmon spent an average of only 0.5 day in potholes during the spring. Steelhead appeared to spend about the same amount of time in potholes as coho salmon (Figure 18), averaging 1.6 days' residence during the summer.

Confidence limits (95%) were computed for each mean residency time value. In general, these confidence limits were wide for each mean residency time (See Appendix E). Standard deviations were also computed for each mean residency time and most were quite large (See Appendix E).

b. Pothole Cover vs. Residence Time

Chinook and coho salmon spent more time in potholes with moderate or heavy amounts of cover than in potholes with no cover (Figure 19). The residence time of coho and chinook in potholes with no cover was only 1/3 to 1/2 the residence time in potholes with more cover (Figure 19). Chum salmon and steelhead trout did not show a preference for potholes of any cover type, although their average residence time increased slightly as cover increased (Figure 19).

c. Pothole Location vs. Residence Time

Chinook, coho, and chum salmon had longer residence time in "isolated" potholes along back sloughs and side channels than in frequently "connected" potholes adjacent to the main river (Figure 20). Steelhead spent about the same amount of time in "isolated" and "connected" potholes (Figure 20).

d. Discussion

Potholes tend to provide juvenile salmonids an area of reduced flow, some protection from predators, preferred rearing habitat, and a potential food supply may be better than other areas of the river or back channels (Woodin et al., 1984). As river flows are reduced, these areas of fish concentration become isolated from the main river. If flows are dropped low enough and held there for prolonged periods of time, the potholes may dry up completely and kill all the entrapped fish.

(1) Spring

Results of the mark-recapture study in the spring of 1985 reveal that chinook and coho salmon fry tend to spend appreciable amounts of time in potholes, while chum salmon are found to spend relatively little time in the potholes by comparison.

FIGURE 18
AVERAGE RESIDENCY TIME OF SALMONID FRY IN POTHOLES BY MONTH (TROUT AND PAULEY, 1985)

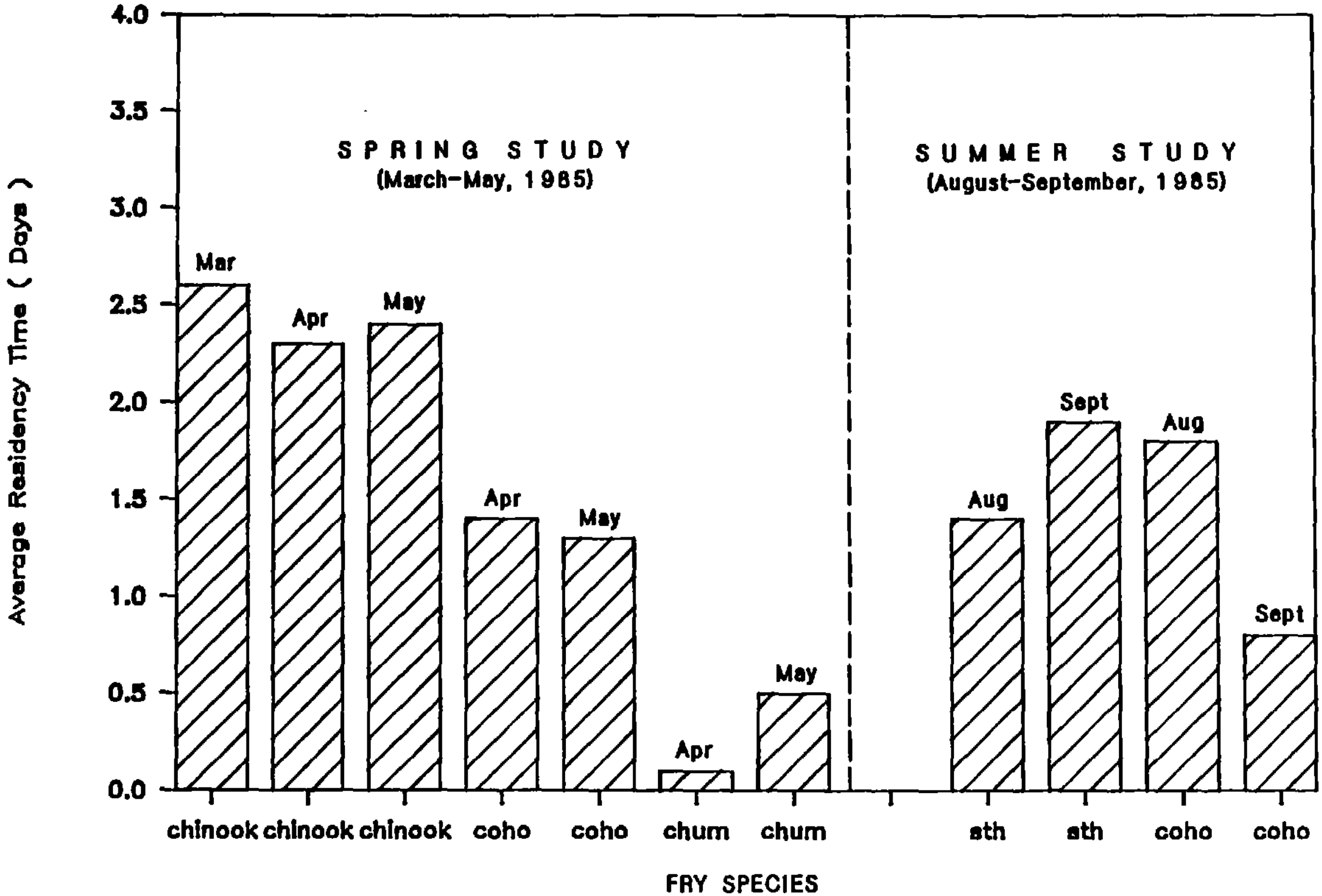


FIGURE 19

AVERAGE RESIDENCY TIME OF SALMONID FRY IN POTHOLES WITH THREE DIFFERENT LEVELS OF COVER (TROUTT AND PAULEY, 1985)

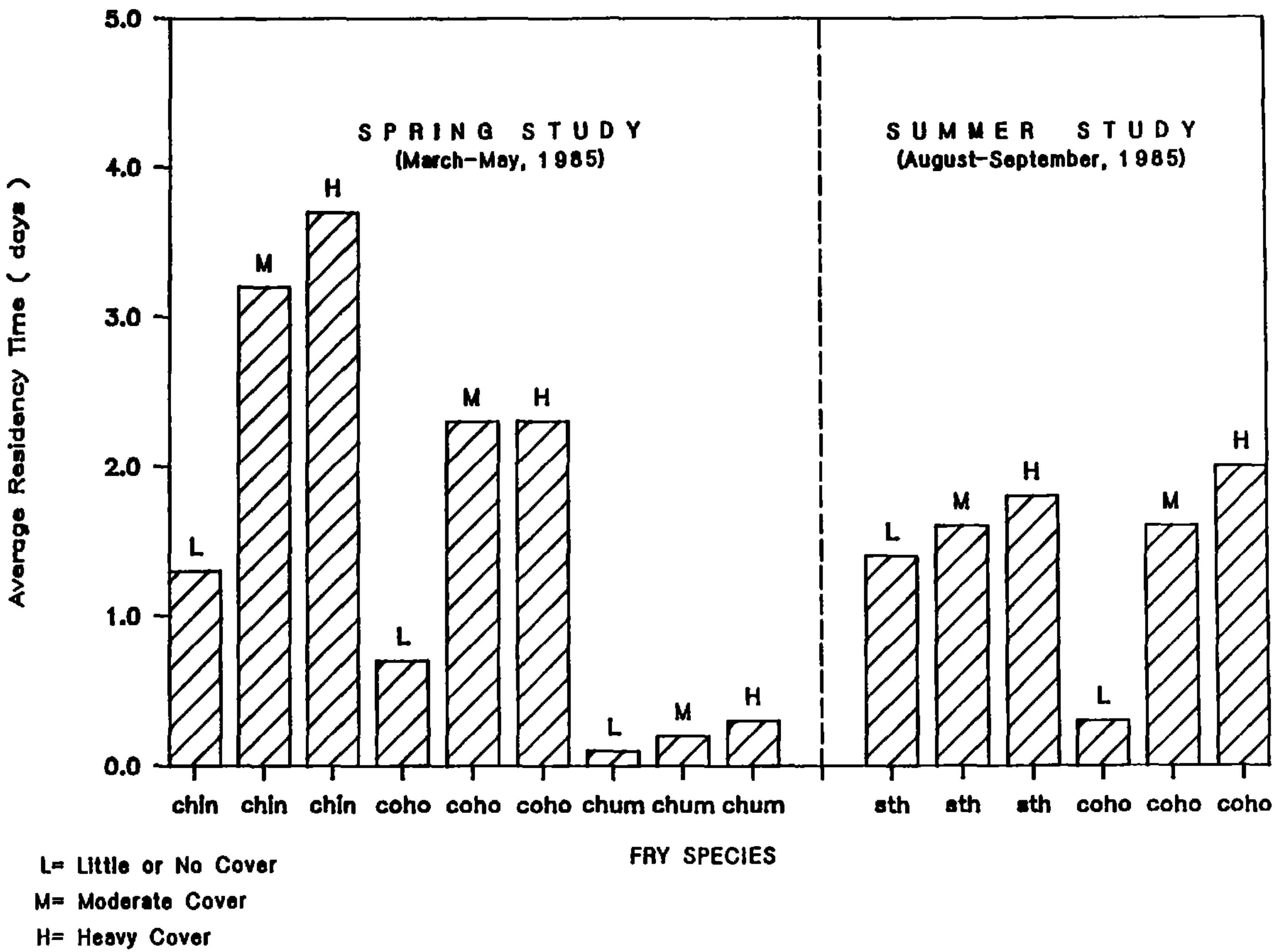
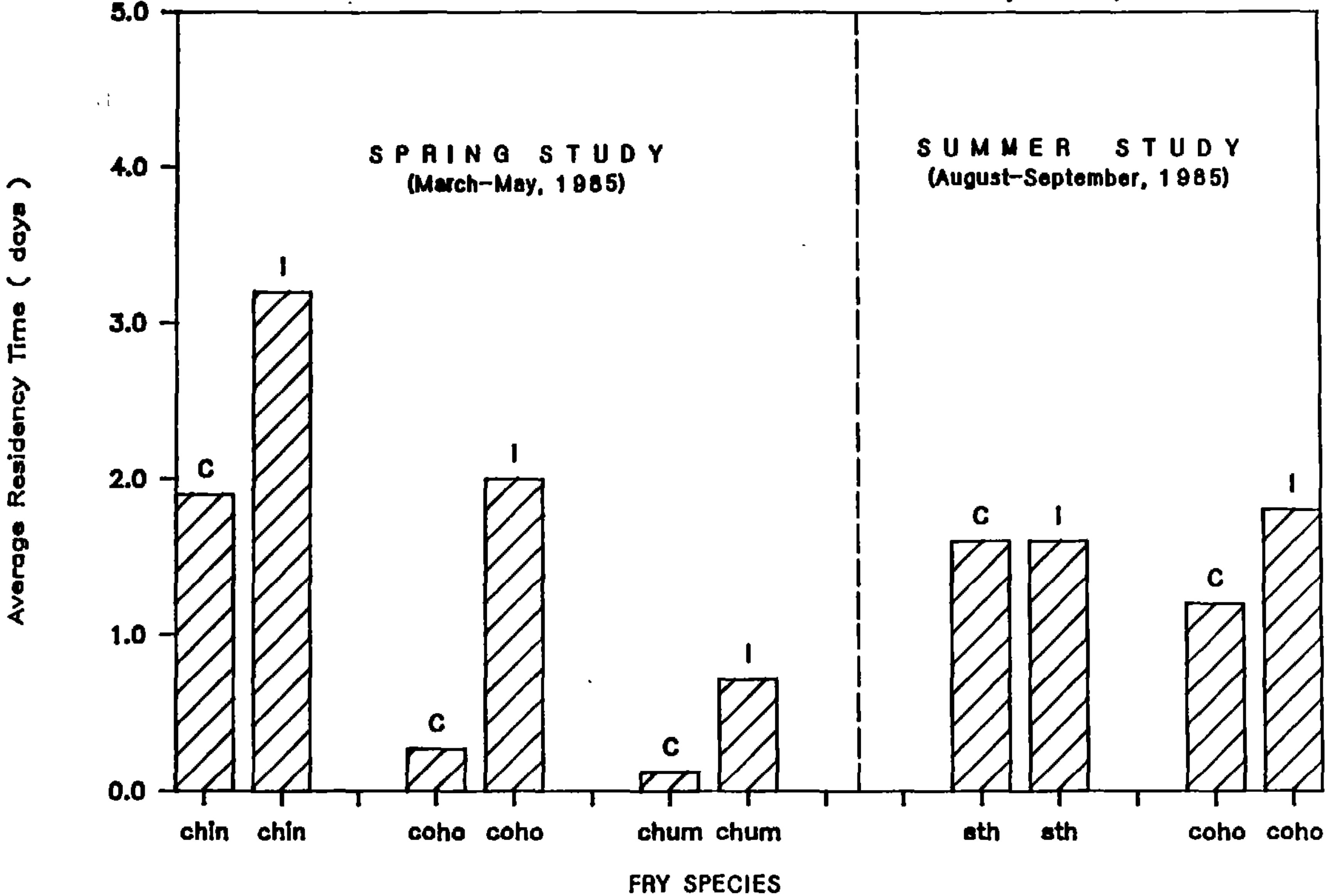


FIGURE 20

AVERAGE RESIDENCY TIME OF SALMONID FRY IN POTHOLES NEAR THE MAIN CHANNEL AND ISOLATED FROM THE MAIN CHANNEL (TROUTT AND PAULEY, 1985)



C= Potholes Near Mainchannel

I= Potholes Isolated From Mainchannel

(a) Chum

Hoar (1956) found that chum salmon fry move immediately downstream toward salt water after emerging from the gravel with the peak outmigration occurring somewhere between the end of April and the middle of May. The short residency time (0.5 day) in the potholes for chum salmon is the approximate time the marked fish are trapped in the potholes immediately after a water level drop, and before the river level rises and reconnects the potholes to the main stream. Of 73 chum salmon marked and released during the spring season, only 3 were recaptured in potholes. Since the residency time in any one pothole is short, individual chum salmon appear to be susceptible to only one downramp cycle in the pothole where they were originally captured.

(b) Chinook

The spring study focused on the movement of juvenile summer-fall chinook salmon. Chinook fry present in the river at this time are the offspring of adults that returned to the upper Skagit River in 1984. Adult fish spawn in September and October in the tailouts of the larger pools in the main river. Chinook fry normally emerge from the gravel in the Skagit River from January through April and the young spend the next 90-110 days in the river before migrating out to Puget Sound (Neave, 1955). It is during this period of freshwater residency that chinook fry are susceptible to pothole trapping and stranding.

Spring study results show that chinook fry spend an average of nearly 2.5 days in the pothole of original capture. Therefore, these fry are susceptible to 2 or 3 downramp event cycles once they enter a pothole. If fry enter and reside in other potholes after leaving the pothole they were marked in, they are again susceptible to multiple downramp events. Recaptures from a release of 235 fish marked with fluorescent dye using the traditional high pressure spray technique of Jackson (1959), seem to indicate that chinook fry become trapped in additional potholes further downstream from the point where they were first trapped and marked. Although 200 fish in a river containing hundreds of thousands of fry is a minuscule amount, 5 of these fish were found a week later concentrated in one pothole almost 2 miles downstream. From this observation, it may be assumed that fry become trapped in a pothole because the habitat, cover, or food is considerably more attractive than the surrounding areas of the river. It is also possible that only a portion of the fish population is attracted to these potholes, hence the high propensity toward recapture of the same individuals. Because of this attraction, the young salmonids may selectively search out similar areas downstream once they move out of earlier potholes that they first encounter.

A comparison of the influence of the physical location of the potholes on length of stay also indicates a trend. Chinook fry spent a full day more in potholes located on side sloughs than in those located along the main river. Lister and Genoe (1970) found that young post-emergence chinook salmon preferred the relatively slow waters found in back eddies and side sloughs. The chinook salmon that we captured in potholes were small post-emergent fry. As the water rises, most of the potholes along the main river are inundated with rapidly moving water, while water in the back slough potholes moves much more slowly.

It is probable that because these back slough areas contain water with less velocity, the fry tend to reside in the potholes located there for the longest time.

Young fry will seek out cover (Lister and Genoe, 1970; Reiser and Bjornn, 1979). Cover appeared to play a role in pothole residency time, with chinook fry residing in potholes with moderate to heavy cover twice as long as in potholes with little or no cover. The combination of adequate cover and slow water is apparently what makes these areas a desired habitat for young chinook salmon.

Chinook fry length was correlated with pothole residency. Chinook fry up to 48 mm total length seemed to be susceptible to pothole trapping and stranding. Only one chinook over 50 mm was captured in a pothole. Upon reaching a length of about 48 mm, chinook fry appear to outmigrate, thus leaving the area of vulnerability. Lister and Genoe (1970) found that as chinook fry in the Big Qualicum River grew larger, they sought out faster water in which to feed.

(c) Coho

Juvenile coho were susceptible to pothole stranding during April and May. These fry were the offspring of coho returning in the fall of 1984. Adult coho spawn primarily in tributaries to the Skagit River above the Sauk River confluence. Coho juveniles emerge in April and May and many move down the tributaries into the Skagit River at that time. Coho fry rear in freshwater for a year or more (Neave 1955).

The residency time of the coho fry at 1.5 days makes them susceptible to 1 or 2 downramp event cycles before they move out of the pothole. Whether or not coho fry move into other potholes after leaving their initial pothole is not clear. In an experiment at Rockport Bar where coho salmon from three adjacent potholes were marked with different colors, none were recaptured in any other pothole once they left their original pothole. The same experiment with chinook fry resulted in the recapture of chinook salmon in different potholes, some of which were upstream from the original pothole. Coho may be adversely affected by potholes and avoid them after an initial experience with them.

Pothole location influenced the length of stay for coho juveniles. Coho fry resided in potholes adjacent to the main river for only 0.3 day, while coho fry in back slough potholes remained 2.0 days. Emerging coho fry seek out the slower water found in back eddies and side sloughs according to Lister and Genoe (1970). This behavior may be a function of water velocity rather than any preference for one pothole over another.

Cover availability also played a large role in coho fry pothole residency. Residency in potholes containing moderate to heavy cover was three times greater than in potholes with little or no cover. This behavior agrees with information concerning habitat selection by coho fry gathered by other investigators (Lister and Genoe, 1970; Reiser and Bjornn, 1979). In this respect, they are like chinook fry, and seek out the slower water present in back sloughs where adequate cover of some sort is present.

The size of coho fry found in potholes also affected their length of residency. Although some yearling coho greater than 80 mm were caught, no age 0 coho over 43 mm were found in potholes during the spring study. Spot shocking of several areas on the main river produced age 0 coho up to 47 mm in May. It appears that, as coho get larger, they seek out faster water (Lister and Genoe, 1970).

(2) <u>Summer</u>

Species composition in potholes shifted from predominantly steelhead in August to a majority of coho in September. Behavioral studies (Chapman, 1965; Frasier, 1969; Lister and Genoe, 1970; Reiser and Bjornn, 1979; Allee, 1981) suggest that emergent coho favor slower water. Emerging steelhead fry seek out slow water, but, as they grow, they reside in faster moving water. Changes in species composition could result either from steelhead fry choosing to move out of potholes, a size induced preference of habitat by one or both species or from steelhead being forced out by the coho fry through competitive interaction (Allee 1981).

(a) <u>Steelhead</u>

Steelhead trout fry trapped in potholes in the summer of 1985 were the progeny of adults returning to the upper Skagit and its tributaries in the summer, fall, and winter of 1984. Adult steelhead spawn sometime between December and June, and fry emerge from July through August. Some of the emergent fry resulting from tributary spawning steelhead make their way down to the Skagit River from August through October, although many steelhead fry spend most of their freshwater residency in the tributaries they were spawned in.

Steelhead fry in the Skagit River, are susceptible to pothole stranding and spend an average of 1.6 days in potholes. This subjects young steelhead to 2 downramping event cycles before they move out of the pothole. Although the average residency time for individual steelhead does not appear to change over the summer season, the actual number of fish stranded became greatly reduced.

Steelhead fry showed no difference in residency time relative to cover concentration of pothole location. This lack of preference may be due to an early attraction to faster water, thereby avoiding potholes, or it may be due to the presence of more aggressive coho salmon which may force steelhead fry out of the potholes as suggested by Allee (1981) and Reiser and Bjornn (1979). This behavior may be a size-related phenomenon as the young coho are larger than the steelhead at this time. Previous fry stranding studies on the Skagit River (Stober et al., 1982) found that there was a dearth of steelhead fry in the nearshore area once they reached 47 mm. In fact, once they reached 40 mm, even though they were still present in the nearshore areas, they became less susceptible to gravel bar stranding (Stober et al., 1982). Stober et al. (1982) found that by October 1, young steelhead had grown to this size and moved out of the potholes. The results of our study, where the actual number of steelhead stranded in potholes dropped substantially from August to September and reached almost zero by the second week of October agree with those of Stober et al. (1982), as no steelhead over 45 mm were found in any potholes during the study. Once fish reach 46 mm they move to areas of the river where they are no longer susceptible to stranding.

(b) Coho

The overall residency time for coho fry in potholes during the summer was nearly 1.5 days. This subjected them to 1 or 2 downramping event cycles. The significant reduction in residency time between August and September may be due to an increase in average size (42 mm in August to 54 mm in September) which may cause the majority of coho fry to move into deeper pools in search of uncrowded space as suggested by Allee (1981).

Coho fry encountered in potholes during the summer season, like those found in the spring study, resided up to five times longer in potholes containing moderate to heavy cover than in potholes with little or no cover. Coho are well known to associate closely with cover.

6. SAUK RIVER SALMON FRY TRAPPING AND STRANDING IN POTHOLES

Most rivers, whether flows are controlled by man or uncontrolled, have potholes associated with them. Until now, this phenomena has not been studied on a uncontrolled river. The purpose of this study task was to first document the presence and location of potholes on an uncontrolled river, the Sauk River, and secondly to qualitatively determine the magnitude of fry trapping and stranding that might normally take place on a river system of this type.

The surveys were conducted on May 11-12, 1985, approximately five days after a high-water event. A total of 19 gravel bar/pothole areas were identified in the 15-mile study area, 15 of which contained potholes. There were a total of 53 potholes identified, 22 of which contained trapped fry. A total of 1,845 fry were counted in these potholes. Trapped fry numbers ranged from a low of 1 to a high of approximately 500. Several potholes were shocked to determine species composition of trapped fry. The majority were chinook fry with lesser numbers of chum fry. Stranded fry were not observed in any of these potholes although it was apparent that stranding would occur if several of the shallow depth (less than 2 inches) potholes containing trapped fry continued to drain as the Sauk River flow dropped.

The results of this one-time survey indicate that pothole trapping does occur on an uncontrolled-flow stream like the Sauk River. The number of trapped fry per pothole in the Sauk River cannot realistically be compared with similar data from the Skagit River because of the Skagit River's almost daily change in stage-discharge resulting from a combination of power generation and precipitation. On the Sauk River, moderate-to-large flow fluctuations do not occur as frequently as on the Skagit River and the rate of flow change is slow compared to what might be considered normal for the Skagit River where up and downramping rates can be controlled. It is clear, however, that relatively large numbers of fry are trapped in the Sauk River potholes as a result of normal flow fluctuations in an uncontrolled river. The most obvious difference between pothole trapping on the Skagit versus the Sauk Rivers is that trapping opportunities happen much more frequently on the Skagit River as a result of dam related water level fluctuations.

SECTION V

RESULTS OF SUMMER/FALL 1985 GRAVEL BAR STRANDING STUDIES

1. BIOLOGICAL FACTORS AFFECTING FRY VULNERABILITY TO GRAVEL BAR STRANDING

During the summer months (July-October), there are primarily two species of salmonid fry, steelhead and coho, that are present in the Skagit River that could be affected by gravel bar stranding. Vulnerability to gravel bar stranding of steelhead and coho fry begins as soon as emergence from the gravel takes place and probably continues until both species leave the Skagit as smolts. The peak vulnerability period, which is when the majority of gravel bar stranding takes place, may only affect a fry species during a particular size or time related period. The major purposes of this study effort were to understand and document the biological window of vulnerability of steelhead and coho fry to gravel bar stranding. A summary of the data collected during the fall and summer 1985 Gravel Bar Stranding Study is found in Appendix F of this report.

a. Species Vulnerability

A total of 2,171 fry were observed stranded on gravel bars during the August 1-20 gravel bar stranding test period. Of this total, 1,784 fry were identified to species; 99.3% were steelhead fry and only 0.7% were coho fry (Figure 21). After the August 1-20 test period, a series of late season gravel bar monitoring surveys were completed. These bi-weekly surveys were conducted on a small number of gravel bars to determine when gravel bar stranding decreased or disappeared. During the late season gravel bar monitoring phase, (August 31-October 5) only 15 stranded fry were observed; all of these fry (100%) were steelhead. It appears that very few coho fry are stranded on gravel bars between August and October. There are two possible explanations for this. Coho fry are not vulnerable to gravel bar stranding or they are not present in dewatered gravel bar habitat. It is clear that coho do not occupy gravel bar habitat based on a comparison of the fry species compositions from the three habitat types sampled; main-channel, back-slough, and potholes. Coho represent 2.6% of the total fry found in main-channel gravel bar habitat and steelhead contribute the remaining 97.4% (Table 12, Figure 21).

The species composition of the main-channel fry population closely resembles the percent distribution of the stranded fry over the same time periods. It appears that each species is stranded in proportion to their density in main channel habitat; the habitat most affected by downramping (Table 13). It is also apparent from these data that steelhead fry are stranded in much higher numbers than coho. In fact, it appears that coho fry are not really vulnerable to gravel bar stranding (Figure 22).

TABLE 12

PERCENT SPECIES COMPOSITION OF FRY
IN THREE DIFFERENT HABITAT TYPES AND STRANDED
ON GRAVEL BARS DURING THE SUMMER 1985
GRAVEL BAR STRANDING STUDY

FRY SPECIES	GRAVEL BAR STRANDED	HABITAT TYPE MAIN-CHANNEL	POTHOLES	BACK-SLOUGH
STEELHEAD	99.2	97.4	55.3	52.4
COHO	0.8	2.6	44.6	47.6

The data show very clearly that because steelhead fry occupy main-channel riffle habitat, which is commonly found covering many of the gravel bar areas studied, it makes them highly susceptible to gravel bar stranding. Conversely, coho fry do not use main-channel habitat and as a result are not affected by gravel bar stranding. Electroshocking data reveal that coho fry are found occupying back-channel and pothole habitats (Table 12). These data are confirmed by many researchers that have documented the habitat preferred by coho, which is characterized by slow velocity, deeper water, and cover-related habitat. Steelhead fry were found in all three habitat types sampled (main-channel, back-slough,and potholes), but were almost exclusively the only species present in main-channel habitat (Figure 21).

b. Biological Window of Vulnerability

Steelhead are highly vulnerable due to their presence in habitat affected by downramping. Coho, on the other hand, do not occupy main-channel habitat and are not affected by gravel bar stranding. These results will deal specifically with steelhead fry and their "biological window of vulnerability".

Size of fry may be one factor that affects fry stranding vulnerability. A comparison of stranded vs. main-channel steelhead fry length frequency distributions was made for early August (August 1-10) and late August (August 11-20) as shown in Table 14. The distribution in Figure 23 shows that stranded steelhead fry length distribution did not change between early and late August. In fact, during both time periods, percent contribution by length interval remained virtually unchanged. This is surprising since the steelhead fry population should be growing over time. The distribution in Figure 14 shows that the main-channel population is growing in length as shown by the upward shift in length frequency distribution from August 1-10 to August 11-20. If gravel bar stranding is not size dependent, then all steelhead fry from emergence to smolt would be affected equally. Conversely, if fry size is an important factor, then the length distribution of fry stranded will not reflect that of the main-channel steelhead fry population. Figure 24 demonstrates that the distributions are different and that steelhead fry are more vulnerable to stranding at smaller sizes. The results of a Chi-square test, which tested

TABLE 13

SKAGIT RIVER STEELHEAD AND COHO DATA FOR DIFFERENT CAPTURE LOCATION TYPES AND TIME PERIODS BETWEEN AUGUST 1 AND OCTOBER 5, 1985

SPECIES	CAPTURE LOCATION TYPE	TIME INTERVAL	FISH NUMBER	AVERAGE LENGTH (cm)	LENGTH RANGE (cm)	STANDARD DEVIATION	VARIANCE
STEELHEAD	Gravel Bar Stranded	August 1 - 10	884	3.25	2.2 - 11.0	0.475	0.210
		August 11 - 20	625	3.27	1.3 - 10.0	0.465	0.216
		August 31 - October 5	15	4.02	3.3 - 4.8	(1)	n/a
	Main Channel (Electroshocked)	August 1 - 10	60	3.58	3.0 - 6.3	0.467	0.218
		August 11 - 20	73	4.08	2.8 - 10.3	145	2.12
		August 31 - October 5	58	3 88	2.9 - 5.2	n/a	n/a
	Potholes (Electroshocked)	August 1 - 10	19	3.5	3.0 - 7.5	0.857	0.918
		August 11 - 20	64	3.53	2.8 - 4.6	0.214	0 045
	Back Channels (Electroshocked)	August 1 - 10	44	3.28	3.0 - 3.9	0.169	0.011
		August 11 - 20	21	3.55	2.8 - 4.4	0.350	0.127
COHO	Gravel Bar Stranded	August 1 - 10	4	5.1	4.5 - 5.8	0.465	0 055
		August 11 - 20	8	4.36	3.4 - 5.4	0.568	0.181
		August 31 - October 5	0	0	0	n/a	n/a
	Main Channel (Electroshocked)	August 1 - 10 NO COHO CAPTURED IN THIS TIME PERIOD					
		August 11 - 20	4	5.8	4.3 - 7.9	1.37	1.89
		August 31 - October 5 NO COHO CAPTURED IN THIS TIME PERIOD					
	Potholes (Electroshocked)	August 1 - 10	57	4.3	3.2 - 7.5	0.795	0 373
		August 11 - 20	10	4.5	3.2 - 6.2	0.695	0 800
	Back Channels (Electroshocked)	August 1 - 10	22	3.8	3 0 - 4.4	0.289	0.835
		August 11 - 20	37	4.2	2.8 - 5.2	0.487	0 237

n/a = Not Applicable   (1) Not Available

FIGURE 21

SPECIES COMPOSITION OF FRY ELECTROSHOCKED FROM THREE DIFFERENT HABITAT TYPES VERSUS THOSE STRANDED ON GRAVEL BARS EXPRESSED AS A PERCENTAGE OF THE POPULATION SAMPLED DURING THE SUMMER 1985 GRAVEL BAR STRANDING STUDY

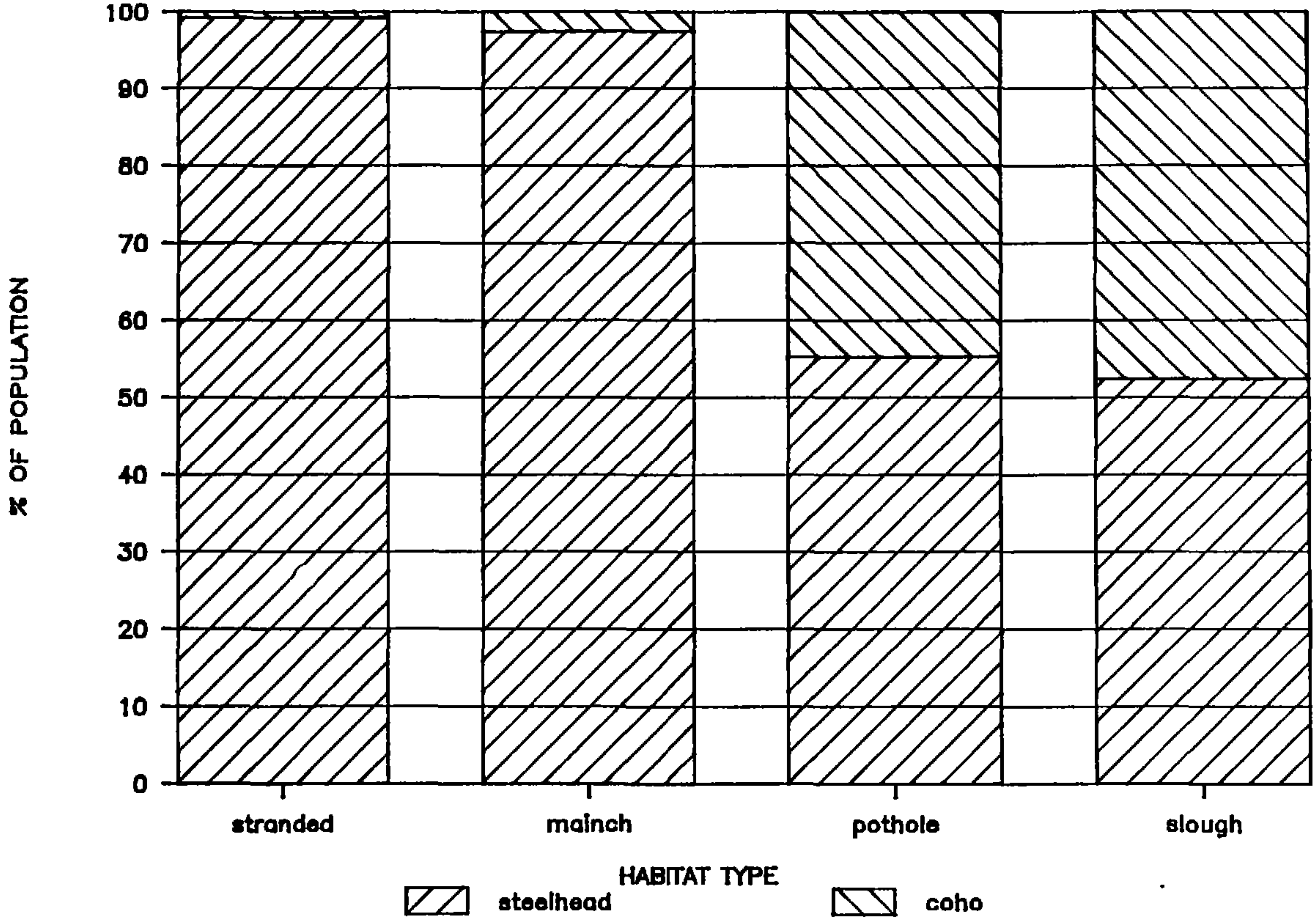


FIGURE 22

FRY COMPOSITION COMPARISON OF STEELHEAD AND COHO GRAVEL BAR STRANDED OR ELECTRO SHOCKED IN MAIN CHANNEL HABITAT DURING THREE TIME PERIODS

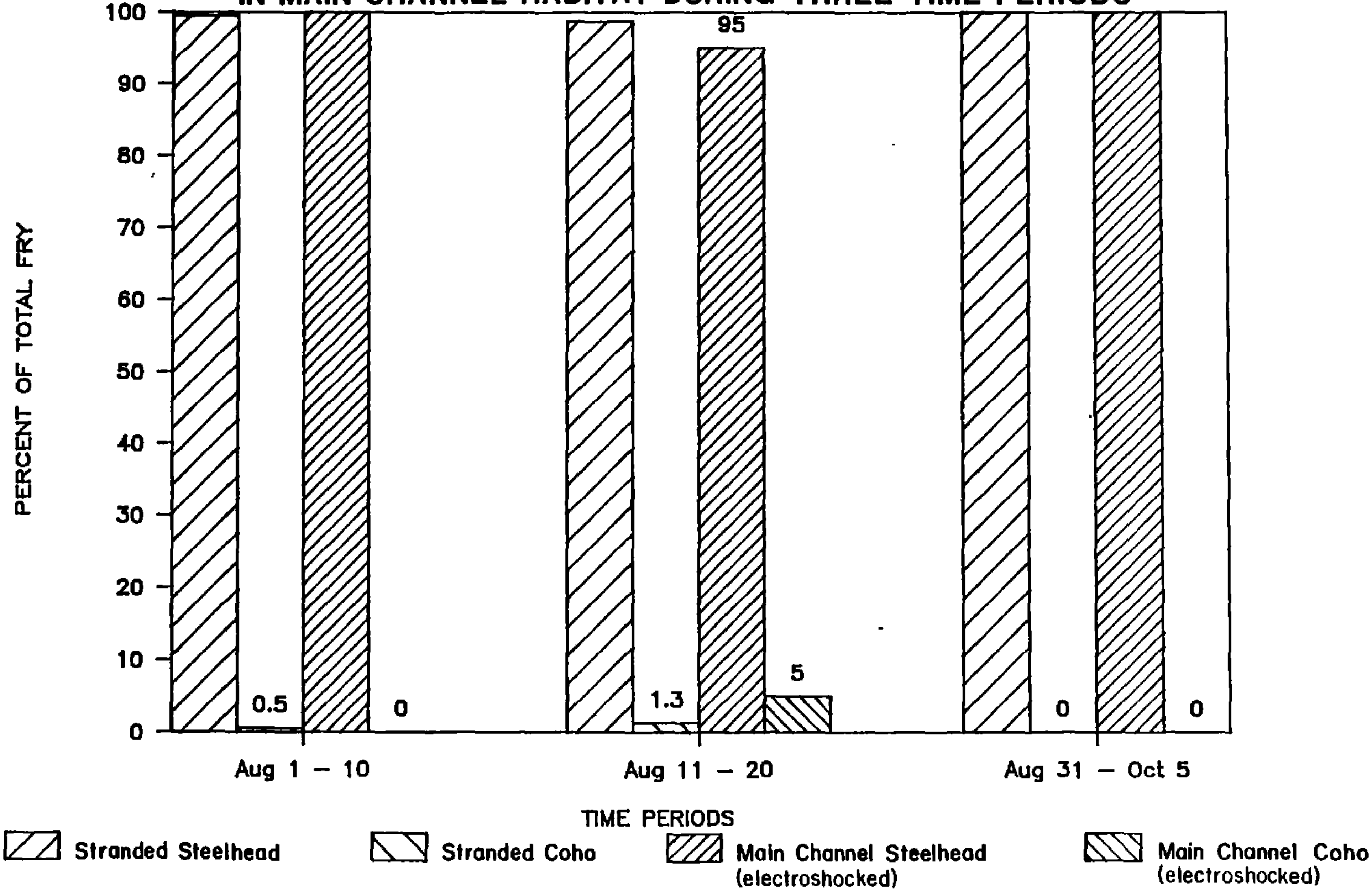


TABLE 14

LENGTH DISTRIBUTION OF STEELHEAD FRY STRANDED ON GRAVEL BARS AND ELECTOSHOCKED FROM MAIN CHANNEL HABITAT EXPRESSED AS A PERCENTAGE OF THE RESPECTIVE SAMPLE SIZE
(data collected from August 1 - 20, 1985.)

FRY SIZE (cm)	GRAVEL BAR STRANDED STEELHEAD FRY DISTRIBUTION (% Of Population)		MAIN CHANNEL ELECTROSHOCKED STEELHEAD FRY DISTRIBUTION (% Of Population)	
	August 1 - 10	August 11 - 20	August 1 - 10	August 11 - 20
0.0 - 0.5				
0.5 - 1.0				
1.0 - 1.5				
1.5 - 2.0		0.5		
2.0 - 2.5		0.2		
2.5 - 3.0	2	2		
3.0 - 3.5	23	20	1	3
3.5 - 4.0	62	63	60	38
4.0 - 4.5	11	12	28	32
4.5 - 5.0	1	2	8	12
5.0 - 5.5	0.2		3	7
5.5 - 6.0	0.2			1
6.0 - 6.5				
6.5 - 7.0			1	
7.0 - 7.5	0.1	0.2		
7.5 - 8.0	0.2			1
8.0 - 8.5				
8.5 - 9.0				1
9.0 - 9.5				
9.5 - 10.0				3
> 10.0				1

FIGURE 23

COMPARISON OF GRAVEL BAR STRANDED STEELHEAD FRY LENGTH FREQUENCIES FOR TWO SAMPLING PERIODS IN AUGUST, 1985

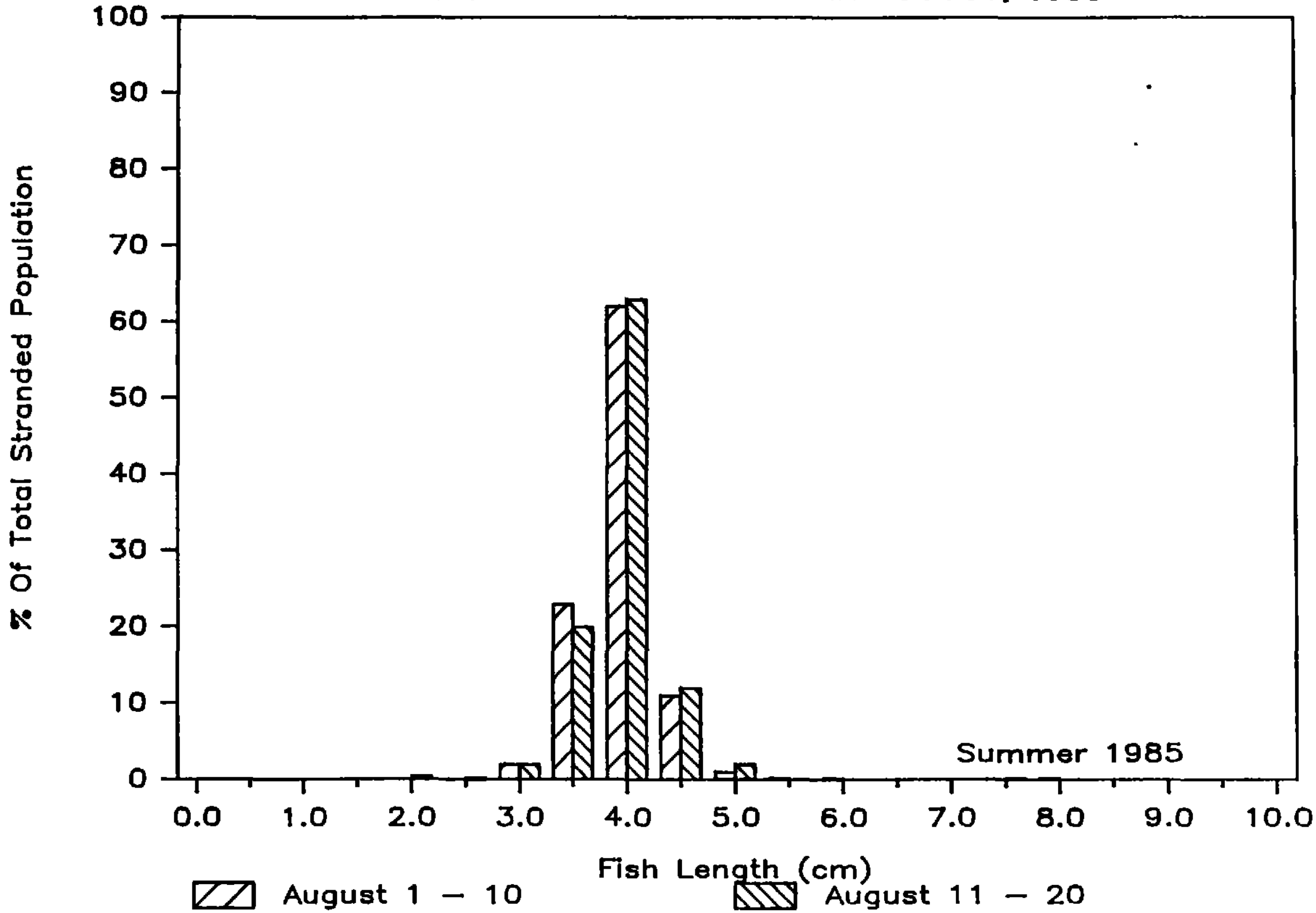
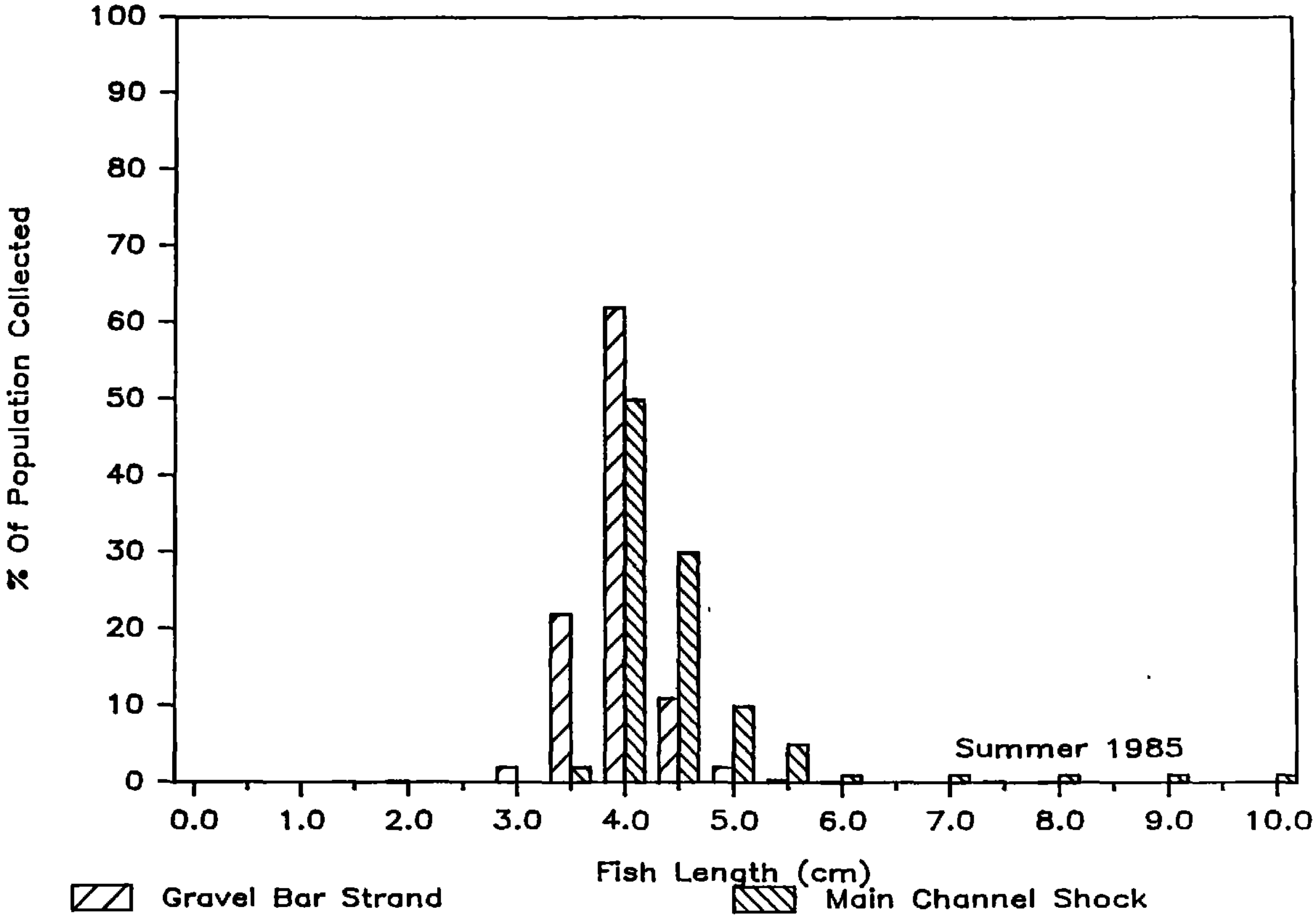


FIGURE 24

COMPARISON OF STEELHEAD FRY LENGTH FREQUENCIES FROM MAIN CHANNEL HABITAT AND GRAVEL BAR STRANDED FRY



main-channel steelhead fry length distributions for the two time periods, found a significant difference between the two distributions (Table 15). The data and results of statistical tests show that as the fry population in the main-channel area grows in late August, the length distribution of stranded fry does not. This evidence strongly suggests that gravel bar stranding of steelhead fry is size dependent.

Comparisons were made using the data from Table 14 to determine which length intervals are most vulnerable to gravel bar stranding. Steelhead fry within length intervals of 3.0-3.5 cm, which represents 1% and 3% of the total steelhead fry population, contributed 23% and 20% to the total stranded population (Table 14). This appears to indicate that steelhead fry of this size are extremely vulnerable to gravel bar stranding. Steelhead fry between 3.5-4.0 cm represented over 60% of all those stranded in both early and late August. However, in early August 60% and in late August 38% of the main-channel steelhead population was made up of 3.5-4.0 cm fry. Once fry size increased above 4.0 cm, vulnerability declined rapidly. This assertion is based again on direct comparison of the proportion of main-channel steelhead fry to stranded fry of the same size interval. Above a fry size of 4.0 cm the percentage of the main-channel population is always found to be much greater than the associated stranded fry of corresponding size as shown in Table 14. Size of peak vulnerability appears to be from emergence to 4.5 cm. Above this size, vulnerability dropped off dramatically (Table 14). Electroshocking results showed that most newly emerged steelhead fry were 3.0 to 3.5 cm in total length, although some fry were observed down to 1.5 cm.

As discussed earlier, three gravel bars were monitored bi-weekly from August 31 to October 5 for stranded fry. Electroshocking was also continued to monitor growth of the steelhead fry population. Table 16 shows the results of these eleven gravel bar surveys. The results of these surveys indicate that stranding continues through September, although stranding occurrences appear to decline, which might be expected since the number of fry in the peak vulnerability size range become reduced as the steelhead fry population continues to grow, combined with a reduction in recruitment of newly emerged steelhead fry. If the emergence timing of the 1985 steelhead brood year was normal, the data collected indicate a window of vulnerability from late July to the end of September. Prior to late July, runoff from snowmelt is typically high and emergence of steelhead is still relatively low. After September most of the steelhead fry were larger than the peak vulnerability size of 4.0 cm.

It should be clearly understood that gravel bar stranding of both steelhead and coho fry likely takes place on a year-round basis; however, outside of the peak vulnerability period this should probably be considered as "background" stranding that affects only a small number of fish relative to those stranded during the peak vulnerability period discussed above. In either case gravel bar stranding of salmonid fry will contribute to reduced productivity.

Table 15 Results Of A Chi-Square Test Of Main-Channel Steelhead Fry Length Distributions For Two Time Periods; August 1-10 And August 11-20

Tabulation of MEDIAN DATE STRANDED (rows) by FRY LENGTH (columns)

Collapsed Table

(Frequency/Row percent/Column percent)

	3	3.5	4	4.5	5	
805	21 2.38 56.76	207 23.44 61.98	547 61.95 58.25	95 10.76 55.88	13 1.47 48.15	883 58.59
815	16 2.56 43.24	127 20.35 38.02	392 62.82 41.75	75 12.02 44.12	14 2.24 51.85	624 41.41
	37 2.46	334 22.16	939 62.31	170 11.28	27 1.79	1507

Statistics for table of MEDIAN DATE STRANDED by FRY LENGTH

Chi-square (4 df) = 3.4006 (P<0.4932)

Tabulation of MEDIAN DATE OF MID-CHANNEL SAMPLE (rows) by FRY LENGTH (columns)

Collapsed Table

(Frequency/Row percent/Column percent)

	4	4.5	5	5.5	
805	49 61.25 62.03	22 27.50 48.89	6 7.50 40.00	3 3.75 21.43	80 52.29
815	30 41.10 37.97	23 31.51 51.11	9 12.33 60.00	11 15.07 78.57	73 47.71
	79 51.63	45 29.41	15 9.80	14 9.15	153

Statistics for table of MEDIAN DATE OF MID-CHANNEL SAMPLE by FRY LENGTH

Chi-square (3 df) = 9.4628 (P<0.0237)

TABLE 16

RESULTS OF LATE SEASON GRAVEL BAR STRANDING SURVEYS
CONDUCTED AT ROCKPORT, MARBLEMOUNT,
AND FUNGUS BARS ON THE SKAGIT RIVER, 1985

Survey Date	Fry Stranded At Bar Site		
	Rockport Bar	Marblemount Bar	Fungus Bar
August 31	0	0	1
September 5	0	3	3
September 7	0	0	0
September 11	0	0	0
September 18	0	2	0
September 21	0	5	0
September 28	0	1	0
October 5	0	0	0
October 12	0	0	0
October 19	0	0	0
Totals	0	11	4

2. PHYSICAL AND HYDRAULIC FACTORS AFFECTING GRAVEL BAR STRANDING

Analysis of variance (ANOVA) using the factors amplitude, ramp rate, slope, substrate size, week, and location (upper vs. lower river sites) showed a significant effect on gravel bar stranding due to each factor with the exception of ramp rate. Several significant interactions (the effect of one factor depends on the level of another) were also present suggesting that effects vary between strata (combination of factor levels). Some of these interactions can probably be attributed to a preponderance of zeros for certain levels of several factors. Table 17 shows the ANOVA table for the middle river observations (RIVLOC=1). Three significant interactions are indicated at alpha = .05 level: two-way interactions between amplitude and slope and between slope and substrate. Significant three-way interactions involve amplitude, slope and substrate. All means for log transformed data are included in Appendix G for further interpretation of interactions.

An ANOVA table was not constructed for the lower study reach (RIVLOC=2) because there were three empty cells in the data to be used in the analysis. However, the general effect of moving downstream is a reduction in hydrologic effects and in steelhead fry stranding as shown in Figures 25-29. The importance of amplitude, slope and river location are very clear and well illustrated in Figures 25-29. Although the data suggest that a ramp rate of 5,000 cfs/hour may strand more fish than a 1,000-cfs/hour rate, the difference, if any, is probably not very large and seems to be confined to certain test strata only. Table 18 shows the ANOVA for all data pooled over ramp rate. The following discussion deals with each factor in greater detail.

Table 17 Analysis Of Variance (ANOVA) Of The Middle Reach For The 1985 Steelhead Fry Gravel Bar Stranding Study

Analysis of Variance — Dependent variable: LOGNUM
For the subgroup: RIVLOC = 1

Source	df	SS (H)	MSE	F	P
Between Subjects	296	413.2348			
A (EVENT)	1	48.7283	48.7283	49.779	0.0000
R (RR)	2	3.9771	1.9886	2.031	0.1326
S (SL)	1	55.9811	55.9811	57.188	0.0000
G (SUBSTR)	1	7.6252	7.6252	7.790	0.0057
W (WEEKN)	2	7.1185	3.5592	3.636	0.0277
AR	2	0.0607	0.0303	0.031	0.9697
AS	1	4.9928	4.9928	5.100	0.0249
AG	1	3.6149	3.6149	3.693	0.0559
AW	2	2.3745	1.1872	1.213	0.2971
RS	2	3.3130	1.6565	1.692	0.1851
RG	2	0.7070	0.3535	0.361	0.6975
RW	4	2.6042	0.6510	0.665	0.6196
SG	1	5.9846	5.9846	6.114	0.0141
SW	2	3.4861	1.7430	1.781	0.1697
GW	2	0.9393	0.4696	0.480	0.6223
ARS	2	1.4200	0.7100	0.725	0.4890
ARG	2	2.4974	1.2487	1.276	0.2792
ARW	4	6.0797	1.5199	1.553	0.1866
ASG	1	4.4926	4.4926	4.589	0.0332
ASW	2	1.3802	0.6901	0.705	0.4989
AGW	2	0.5091	0.2546	0.260	0.7729
RSG	2	0.2672	0.1336	0.136	0.8734
RSW	4	3.6893	0.9221	0.942	0.4445
RGW	4	1.4425	0.3606	0.368	0.8322
SGW	2	1.3089	0.6545	0.669	0.5170
ARSG	2	3.5618	1.7809	1.819	0.1633
ARSW	4	6.0408	1.5102	1.543	0.1894
ARGW	4	1.0384	0.2596	0.265	0.9008
ASGW	2	3.4034	1.7017	1.738	0.1769
RSGW	4	0.0725	0.0181	0.019	0.9993
ARSGW	4	4.2730	1.0682	1.091	0.3590
Subj w Groups	225	220.2516	0.9789		

A = Event
R = Ramping Rate
S = Slope
G = Substrate
W = Week

Table 18 Analysis Of Variance (ANOVA) For All Data (Including Day/Night) Pooled Over Ramping Rate For The 1985 Steelhead Fry Gravel Bar Stranding Study.

Analysis of Variance   Dependent variable: LOGNUM

Source	df	SS (H)	MSS	F	P
Between Subjects	595	589.4990			
R (RIVLOC)	1	53.7177	53.7177	89.954	0.0000
A (A)	1	54.1560	54.1560	90.688	0.0000
S (SL)	1	76.4109	76.4109	127.955	0.0000
G (SUBSTR)	1	5.0444	5.0444	8.447	0.0038
W (WEEKN)	2	11.8826	5.9413	9.949	0.0001
RA	1	7.6177	7.6177	12.756	0.0004
RS	1	3.5703	3.5703	5.979	0.0148
RG	1	1.4938	1.4938	2.501	0.1143
RW	2	0.7877	0.3939	0.660	0.5210
AS	1	11.4495	11.4495	19.173	0.0000
AG	1	3.1851	3.1851	5.334	0.0213
AW	2	1.1268	0.5634	0.943	0.3943
SG	1	0.9161	0.9161	1.534	0.2161
SW	2	3.1665	1.5833	2.651	0.0709
GW	2	1.4577	0.7289	1.221	0.2937
RAS	1	0.0154	0.0154	0.026	0.8728
RAG	1	0.9450	0.9450	1.582	0.2090
RAW	2	1.9789	0.9894	1.657	0.1903
RSG	1	6.7312	6.7312	11.272	0.0009
RSW	2	2.2529	1.1265	1.886	0.1515
RGW	2	0.2507	0.1253	0.210	0.8121
ASG	1	1.0630	1.0630	1.780	0.1827
ASW	2	1.1969	0.5984	1.002	0.3651
AGW	2	0.3178	0.1589	0.266	0.7682
SGW	2	0.4219	0.2110	0.353	0.7047
RASG	1	4.2033	4.2033	7.039	0.0082
RASW	2	1.2405	0.6203	1.039	0.3520
RAGW	2	0.2885	0.1442	0.242	0.7871
RSGW	2	1.0739	0.5370	0.899	0.4118
ASGW	2	2.0736	1.0368	1.736	0.1759
RASGW	2	2.2134	1.1067	1.853	0.1566
Subj w Groups	548	327.2494	0.5972		

FIGURE 25

STACKED BAR GRAPHS SHOWING THE EFFECT OF DOWNRAMP AMPLITUDE ON STEELHEAD FRY GRAVEL BAR STRANDING AT DIFFERENT LEVELS OF OTHER TESTING FACTORS

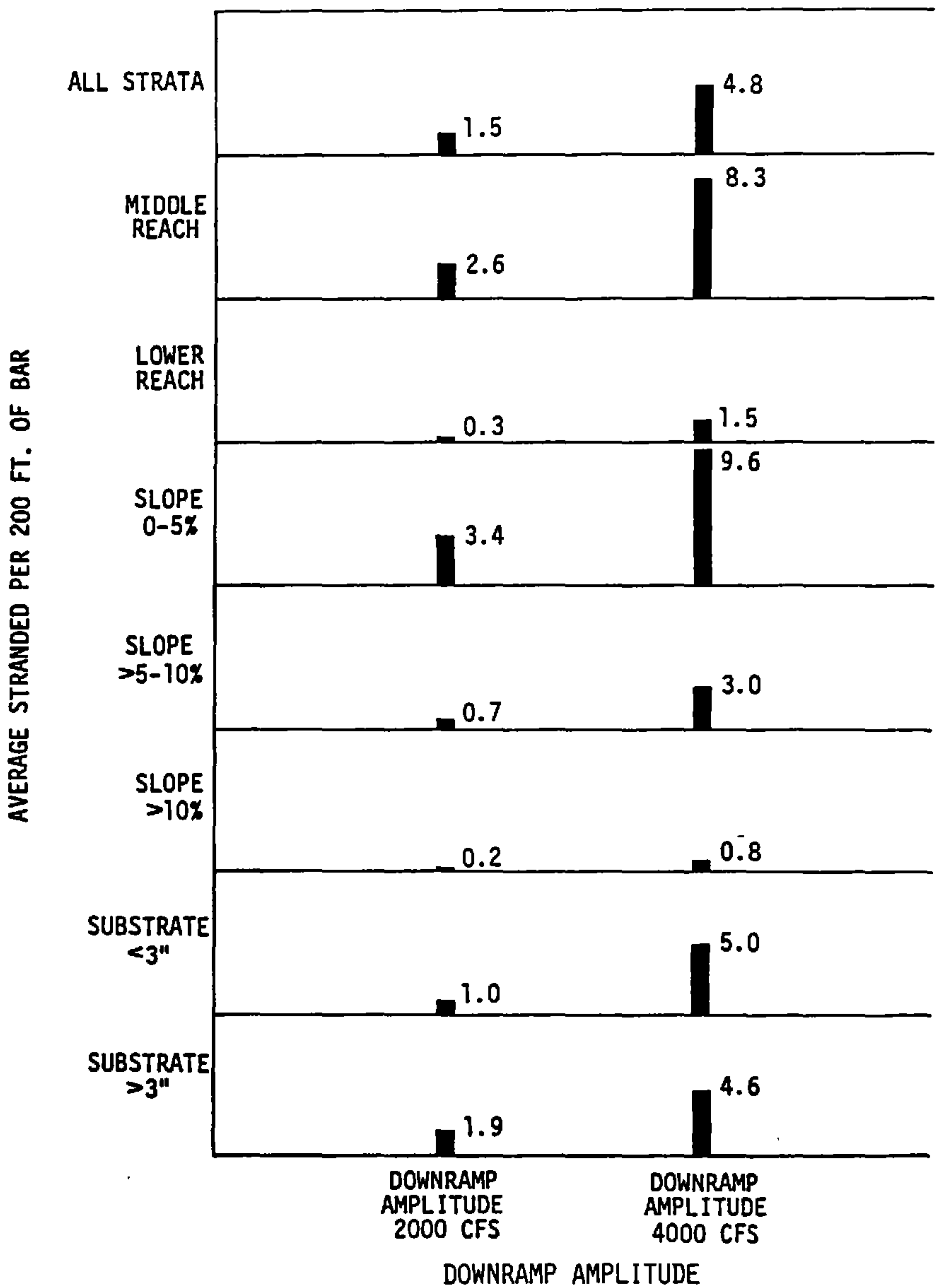


FIGURE 26

STACKED BAR GRAPHS SHOWING THE EFFECT OF RATE OF DOWNRAMPING ON STEELHEAD FRY GRAVEL BAR STRANDING AT DIFFERENT LEVELS OF OTHER TESTING FACTORS

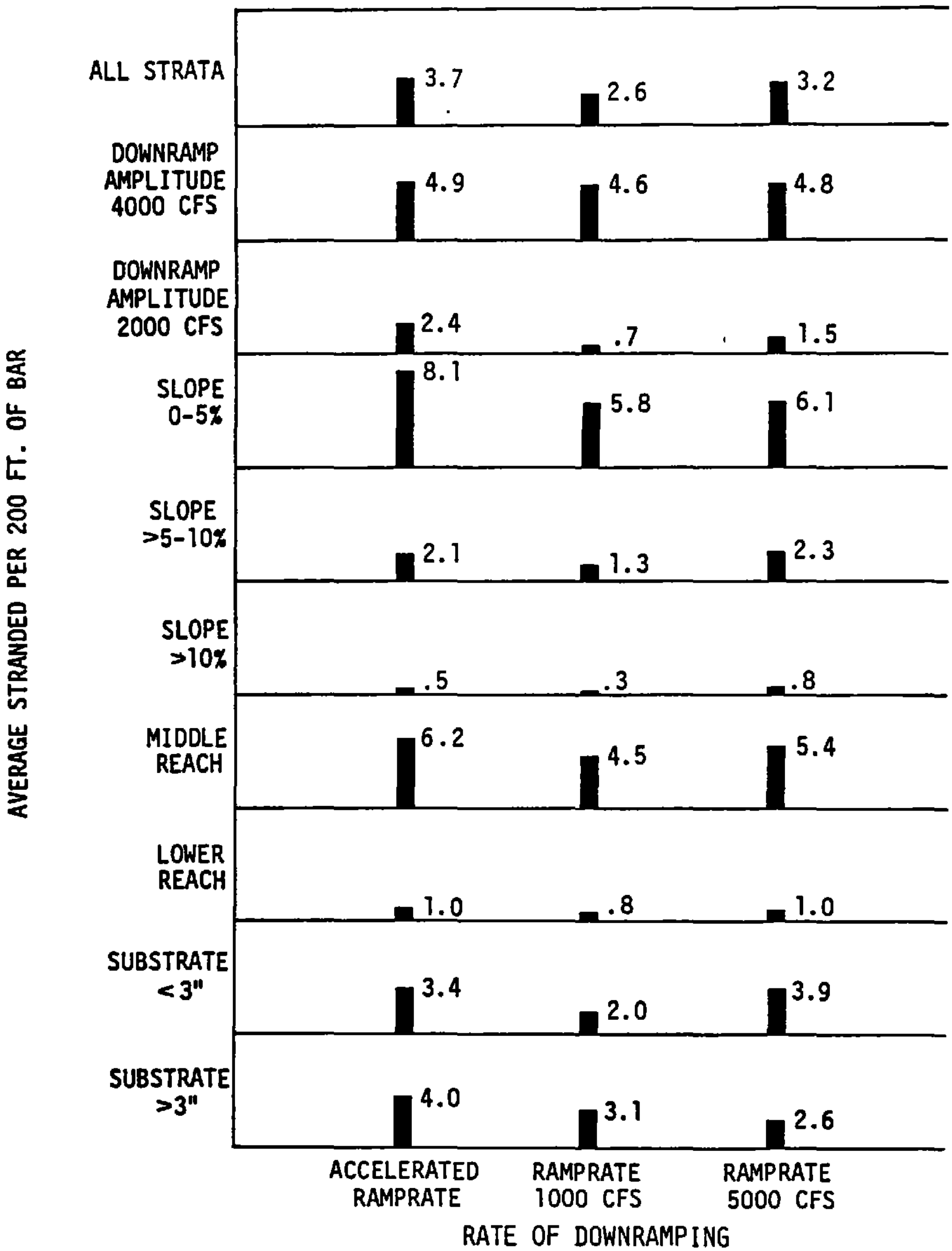


FIGURE 27

STACKED BAR GRAPHS SHOWING THE EFFECT OF SLOPE ON STEELHEAD FRY GRAVEL BAR STRANDING AT DIFFERENT LEVELS OF OTHER TESTING FACTORS

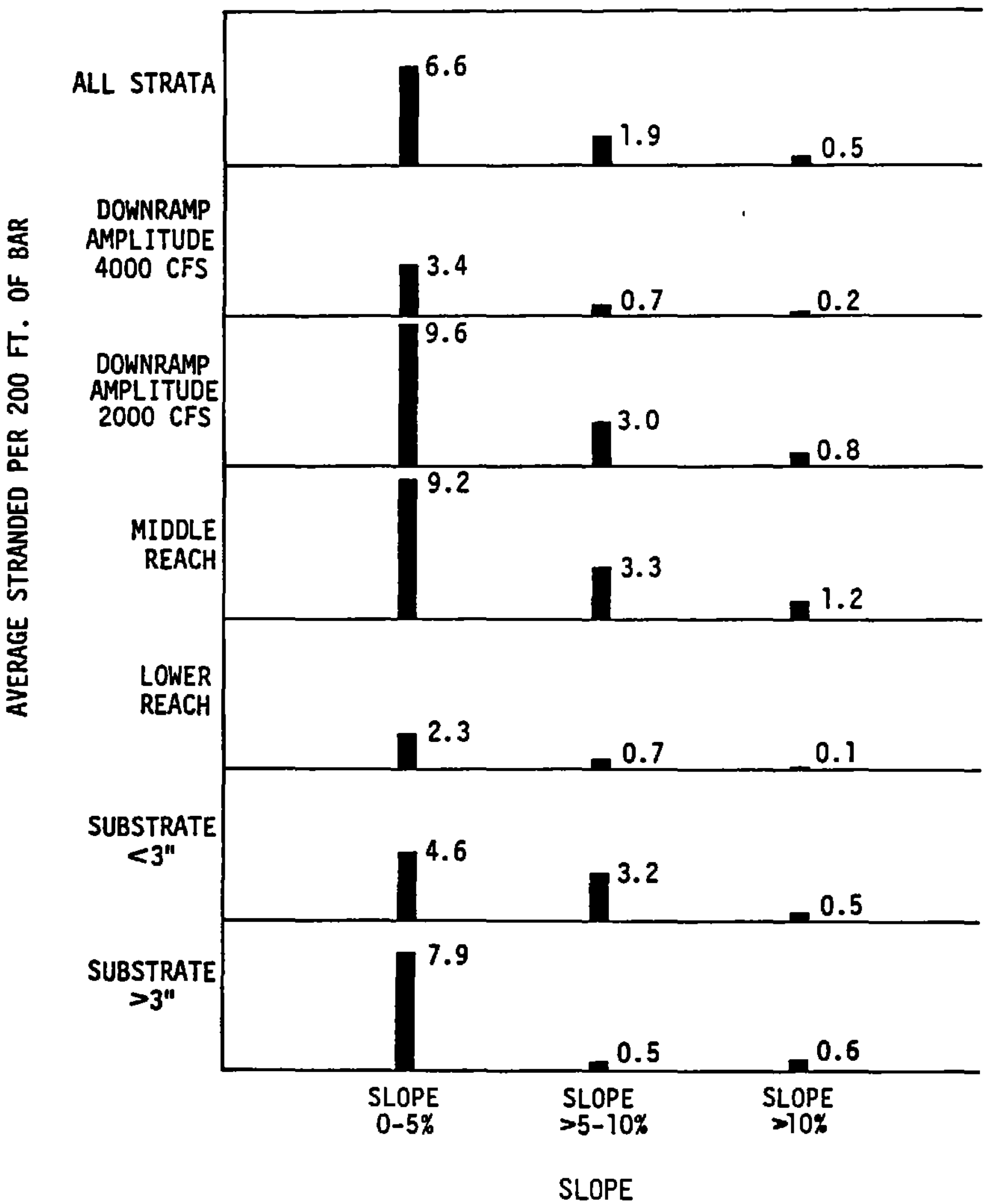


FIGURE 28

STACKED BAR GRAPHS SHOWING THE EFFECT OF RIVER LOCATION ON STEELHEAD FRY GRAVEL BAR STRANDING AT DIFFERENT LEVELS OF OTHER TESTING FACTORS

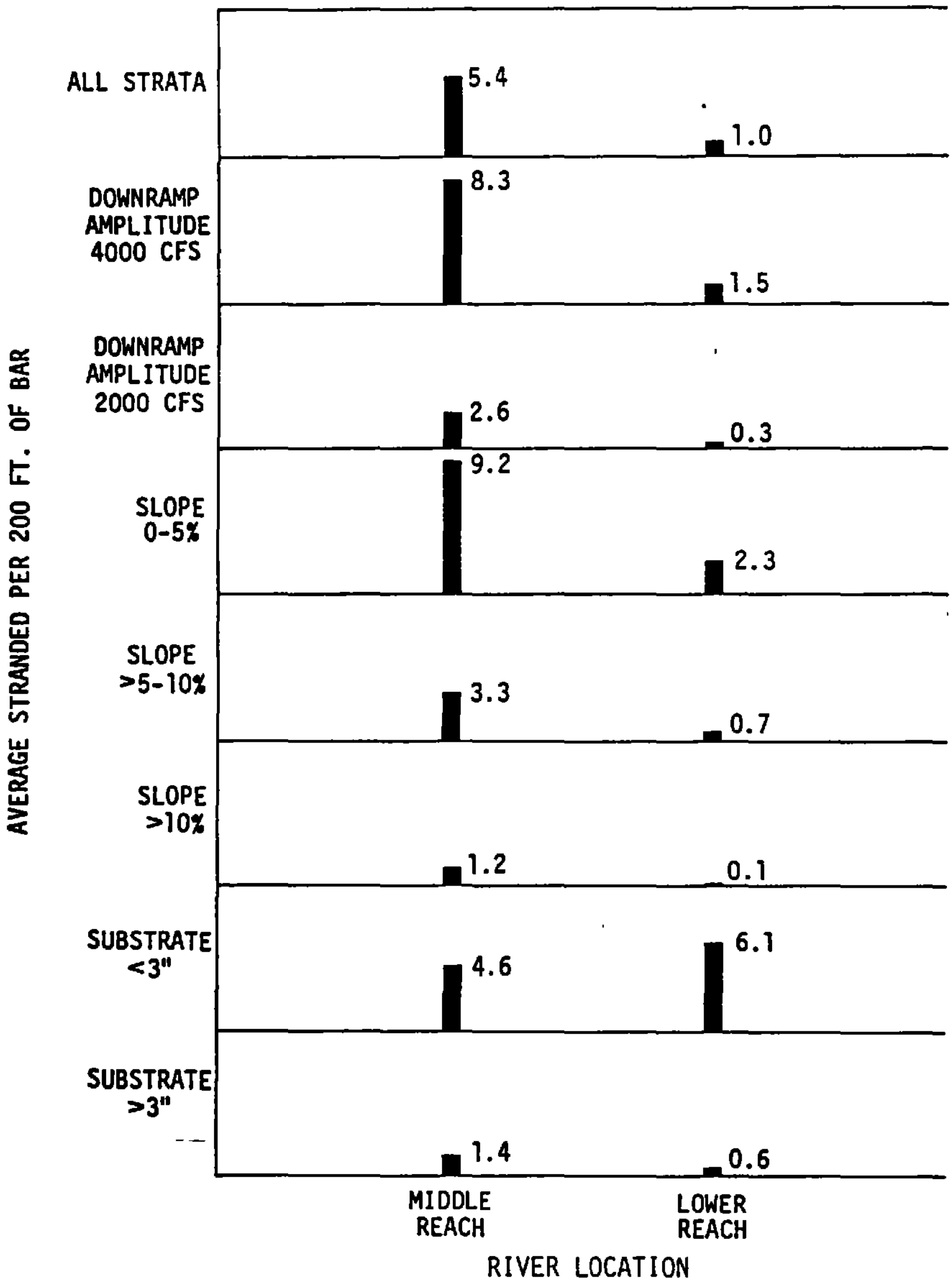
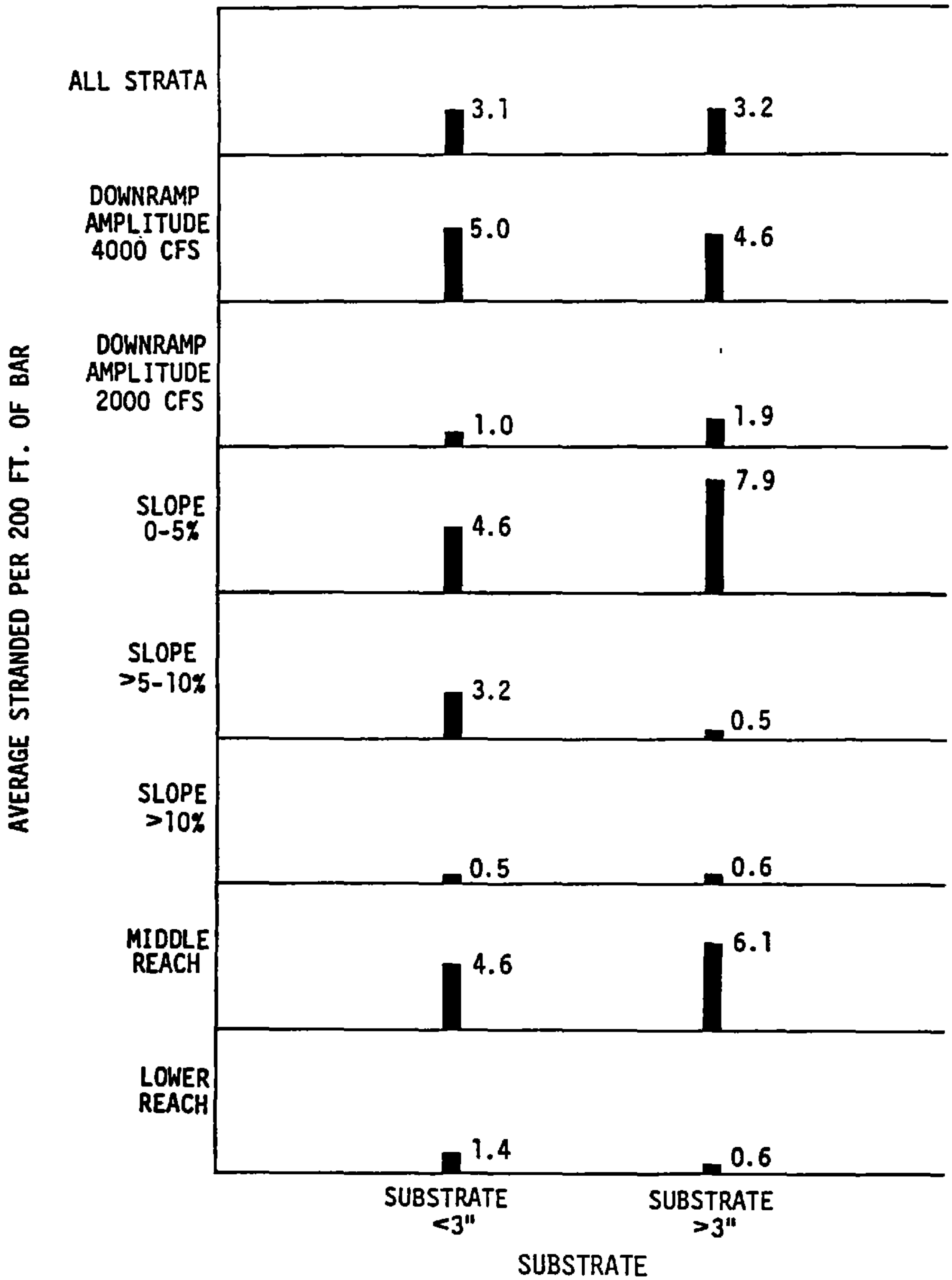


FIGURE 29

STACKED BAR GRAPHS SHOWING THE EFFECT OF SUBSTRATE ON STEELHEAD FRY GRAVEL BAR STRANDING AT DIFFERENT LEVELS OF OTHER TESTING FACTORS



a. Amplitude

Stranding during a 4,000-cfs amplitude downramp is significantly higher than for a 2,000 cfs downramp. In fact the 4,000-cfs amplitude consistently stranded more than twice the number of fry stranded by the 2,000-cfs amplitude fluctuation (see ANOVA Table 18 and Figure 25).

Furthermore, larger numbers of fry were stranded during the last half of a 4,000-cfs downramp than during the first half. The latter result is consistent with the theory that stranding is proportional to the amount of habitat dewatered, since the area dewatered per cfs withdrawn increases as flow decreases.

The endflows during all tests were about 2,500 cfs at Marblemount, consequently a 2,000-cfs amplitude test dewatered more than half the area of a 4,000-cfs amplitude test. Thus, the fact the 4,000-cfs amplitude tests stranded more than twice as many fry as the 2,000-cfs amplitude tests suggests that area exposed can not alone explain this difference. There is a definite tendency for fry to become stranded towards the end of a downramping event. This tendency is stronger for a large amplitude than for a small amplitude event.

b. Ramp Rate

The ANOVA tests failed to show a significant effect due to the ramp rates used. (See ANOVA Table 17 and Figure 26). A more detailed discussion of ramping rate is presented later in this section of the report as part of fry stranding location relationships.

c. Gravel Bar Slope

Gravel bar slope shows a very clear relationship to stranding of fry on gravel bars. Gravel bars with a slope less than 5% were responsible for the majority of all stranding. (See ANOVA Table 18 and Figure 27). The slope of the bar exposed is also an indirect measure of the habitat dewatered. The smaller the slope, the greater the amount of habitat dewatered for a given downramp.

Slope also has an effect on the rate of habitat dewatering (the smaller the slope, the faster the rate of dewatering) and, therefore, has an effect similar to ramping rate. The overall results of this study suggest that the amount of habitat dewatered is far more important to steelhead stranding than the rate of habitat dewatering within the ranges tested.

d. Location On River ("River Location")

Consistent with the results for slope and amplitude is that the effects of any downramping event are far greater upstream where the relative volume of water involved is greater. (See ANOVA Table 18 and Figure 28). Considerably less stranding downstream of Marblemount may in part be due to other factors (e.g., fry distribution) but the stabilizing effects of increased tributary inflow no doubt dampen the impact of downramping events.

e. Substrate

The ANOVA rates substrate as significant. Smaller substrate (less than 3 inches) generally tends to strand more than coarse (greater than 3 inches). ANOVA Table 17 and Figure 29 which shows the untransformed means suggests a more complex relationship with, for example, some reverse effects between different levels of slope, river reach, and amplitude. The general conclusion about substrate size is that it does seem to affect stranding and should be accounted for in the analysis although its effects are not clearly understood.

f. Daylight vs. Night Downramping

Paired t-tests were performed by test site and date for 116 pairs of observations. Although the average number stranded during the night tests was somewhat greater, the difference was not significant for transformed or untransformed data. The Wilcoxon Signed Ranks test also failed to show any significant difference between daylight and darkness stranding for steelhead. Table 19 summarizes the day/night test results. Statistical tables are shown in Appendix H.

TABLE 19

RESULTS OF A WILCOXON SIGNED-RANKED TEST
OF DAYLIGHT VERSUS DARKNESS DOWNRAMPING
TIMES ON STEELHEAD FRY (1985)

Date	Ramping Rate		Average Number of Fry Stranded		No. of Observations	P - Value of
	Darkness	Daylight	Darkness	Daylight	N	Signed Ranks Test
8/02	R2	R2	5.41	4.12	17	0.859
8/11	R2	R2	0.94	0.77	34	0.591
8/12	R3	R3	1.18	1.65	34	0.975
8/16	R1	R3	0.26	0.48	31	0.176
All Dates	--	--	1.48	1.44	116	0.932

It might be argued that observations at the Diobsud Creek, Site 1 should be excluded from the analysis since most of the stranding at this site occurred in a large pothole-like feature in the upper part of the bar. However, excluding these observations did not affect the conclusions. It should be noted that the day and night portions of the tests involved different levels of each site. The night stranding always occurred above the day stranding. Analysis of double tests conducted entirely in darkness indicated that stranding in the later test segment tended to be either greater to or equal to the earlier one (results were dependent upon ramp rate). Thus, it can probably be safely concluded, on the basis of the analysis tabulated above, that daylight downramping does not increase steelhead stranding.

3. FRY STRANDING LOCATION RELATIONSHIPS

The precise location of a stranded fry could be influenced by a variety of hydrologic, physical and temporal factors such as ramp rate, amplitude fluctuation, time of day, or physical features on the bar. Relating the stranding locations to these factors could provide further insight into the understanding of gravel bar stranding phenomena. The purpose of this task was to explore gravel bar stranding location with respect to these factors.

The results of this work will be presented in several parts each dealing with different types of controlling factors as follows:

- Fry stranding locations vs. gravel bar features
- Fry stranding locations vs. night or day downramping times
- Fry stranding locations vs. downramping-rate

(1) Fry Strand Location vs. Gravel Bar Features

Seventeen of the 35 gravel bar stranding test sites had measurable features. Only 13 of these 17 had fry stranded on them. This experiment tested the hypothesis that the location of stranded fry is closely associated with the physical features of a gravel bar. Seven different types of physical features were identified: (1) potholes; (2) logs; (3) wood debris piles; (4) large rocks; (5) vegetation lines; (6) auto part debris; and (7) channel depressions. (See Legend in Appendix I).

Twelve gravel bar sites were graphed showing the locations of all fry stranded on each site during the course of the study, physical features and the average high and low waterlines of the 4,000-cfs amplitude tests. In most cases, a visual examination indicates that there is no strong correlation between gravel bar features and the location of stranded steelhead fry. (See Appendix I). The only exceptions were fry stranded in potholes, such as those shown at Marblemount Bar, Site 3. There were a total of 17 potholes, only 4 of which trapped one or more fry. Fry were also stranded in all four of the channel depressions identified on Forbidden, Diobsud, and Oink Bars.

Fry did not appear to strand in or around woody debris piles, logs, or vegetation lines found on most of the 12 feature bars. It seems that most of the fry stranded were not associated with any particular bar feature except those trapped in potholes and channel depressions, both of which trap fry before they strand them unlike the other feature types. The 12 gravel bar plots indicate that there is no strong correlation between stranding location and physical features on the gravel bars, although potholes and channel depressions did strand a small number of fry.

(2) Fry Stranding Location vs. Ramp Rate

The major purpose of this task was to explore possible patterns in fry stranding distribution in relation to the three downramping rates used during the gravel bar stranding tests.

(a) 1,000 cfs/hour vs. 5,000 cfs/hour

Figures J-1 to J-8 in Appendix J are graphical plots of the gravel bar sites stranding more than 3 fry, with 4,000-cfs amplitude fluctuations and 1,000 cfs/hour ramp rate. Figures J-9 to J-19 in Appendix J are the same plots with 5,000 cfs/hour ramp rates. A comparison of these plots indicates that there are no differences between the distributions of stranded fry regardless of ramp rate. The original speculation was that as the ramp rate increased from 1,000 to 5,000 cfs/hour, the fry would become stranded closer to the high waterline as a result of a faster gravel bar dewatering rate. This relationship, however, does not appear to hold since the typical distribution of stranded fry appears to be random rather than stratified.

(b) Accelerated vs. Constant Ramping Rate

Figures K-1 to K-15 in Appendix K are graphical plots of gravel bar sites showing the distribution of stranded fry resulting from 4,000-cfs amplitude fluctuations with an accelerated rate and then again with a 5,000-cfs/hour constant ramp rate. The accelerated ramp rate was accomplished by withdrawing the first 1,500 cfs at a rate of 500 cfs/hour and the remaining 2,500 cfs at 5,000 cfs/hour. The hypothesis was that the accelerated rate might strand less fry by beginning the downramp at a slower rate followed by a faster rate compared with a constant ramp rate of 5,000 cfs/hour. The results were also compared with a constant ramp rate of 1,000 cfs/hour.

Nine (9) tests were conducted where the amplitude of the downramp was approximately 4,000 cfs. (See test schedule in Table 3). Thirty five gravel bar sites were surveyed after each test.

Based on the measured coordinates of observed fry casualties and intermediate waterlines, the fry counts were divided into two categories. Thus, separate estimates were obtained of the numbers stranded during the first and last 2,000 cfs of the complete downramp.

A total of 307 paired (first and last 2,000 cfs) observations were thus obtained (8 out of the possible 315 observations were missing). The average distribution of fry stranding between the two downramping stages is shown in Table 20. The lack of a significant difference in overall stranding (total 4,000 cfs) between the three ramping rate schemes tested is noteworthy along with the apparent difference between ramp rates during the first 2,000 cfs.

TABLE 20

AVERAGE NUMBER OF STEELHEAD STRANDED ON GRAVEL BARS
DURING 4000 CFS AMPLITUDE TESTS IN 1985

DOWNRAMP STAGE	RAMP RATE	MIDDLE RIVER	LOWER RIVER	MIDDLE & LOWER RIVER COMBINED	KRUSKAL-WALLIS P-VALUES
FIRST 2000 CFS	R1	1.66	0.26	0.93	a) .040
	R2	4.15 } a	0.58 } b	2.27 } c	b) .044
	R3	4.67	1.04	2.82	c) .004
LAST 2000 CFS	R1	6.80	1.26	3.92	a) .195
	R2	4.13 } a	0.62 } b	2.28 } c	b) .637
	R3	3.52	0.70	2.09	c) .198
TOTAL 4000 CFS	R1	8.46	1.52	4.86	a) .504
	R2	8.28 } a	1.18 } b	4.56 } c	b) .211
	R3	8.19	1.74	4.91	c) .185

R1 = ACCELERATED RAMPING RATE

R2 = CONSTANT 1000 CFS/HR

R3 = CONSTANT 5000 CFS/HR

Figures 30 and 31 further reveal three different stranding profiles for the three ramp rates: (1) accelerated ramp rates result in accelerated stranding; (2) constant downramping at 1,000 cfs/hr produces constant stranding over time; (3) constant downramping at 5,000 cfs/hr results in a decreasing rate of stranding over time. The results of paired t-tests and Wilcoxon Signed Ranks tests for the data pairs shown in Figures 31 and 32 are presented in Appendix L.

It is important to stress that these results apply to the full 4,000 cfs downramp amplitudes tested. It should not be concluded, for example, that terminating the test after the first 2,000 cfs would yield the stranding profiles observed here. In fact, tests at 2,000 cfs of amplitude suggest that ramping rate may affect the pattern of stranding over time (within downramp event) without dramatically affecting the final count. (See Table 21).

Some general comments on these results are in order. As would be expected, the trends are much more apparent in the upper part of the study area where the hydrologic effects are more exaggerated. For example, the results seem to support a theory that fry stranding is primarily a function of the area dewatered (i.e., amplitude) and that ramping rates between 1,000 and 5,000 cfs/hr produce similar results. In fact, the results do not contradict this conclusion for ramping rates as low as 500. The effect of sustaining a 500 cfs ramping rate has, however, not been examined.

TABLE 21

GRAVEL BAR STRANDING
WITH DOWNRAMP AMPLITUDE
OF APPROXIMATELY 2,000 CFS(1)

Ramp Rate	Middle River	Lower River	Middle and Lower River Combined
Accelerated	3.94	0.25	2.38
1,000 cfs/hr	1.04	0.42	0.72
5,000 cfs/hr	2.77	0.30	1.55

(1) - See Appendix M for statistical test results.

Two elements of these test results are very important. First, the rate of stranding in the 500-cfs/hour portion of the bar was lower than the corresponding stranding rates for either 1,000 or 5,000-cfs/hour ramp rates. Secondly, the total number of fry stranded for each test were roughly the same regardless of ramp rate. The lower stranding rate produced by the 500-cfs/hour ramping rate is particularly significant since there was no difference in stranding rate between the 1,000 and the 5,000 ramp rates. This difference can be interpreted to mean that stranding rates do not change between 1,000 and 5,000 cfs/hour, but between 1,000 and 500 cfs/hour the rate of stranding may be reduced. From a fry behavioral standpoint, it means that at 500 cfs/hour, a vulnerable fry may be able to avoid becoming stranded by following the waters edge as it recedes. It also indicates that there might be some safer levels of

FIGURE 30

AVERAGE NUMBER OF STEELHEAD FRY STRANDED ON GRAVEL BARS DURING THE FIRST AND SECOND HALF OF 4000 CFS AMPLITUDE DOWNRAMP TESTS IN THE MIDDLE STUDY REACH

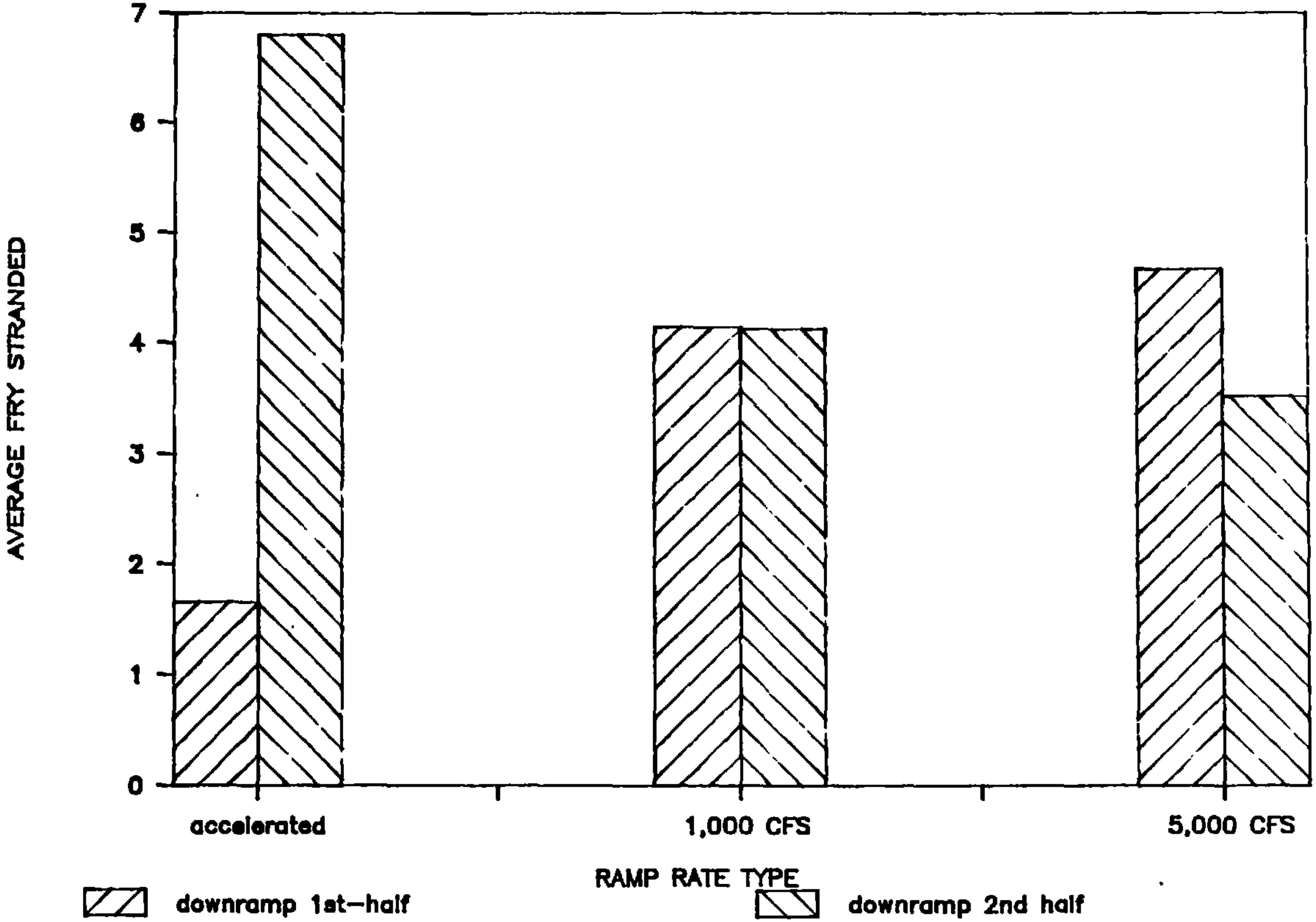
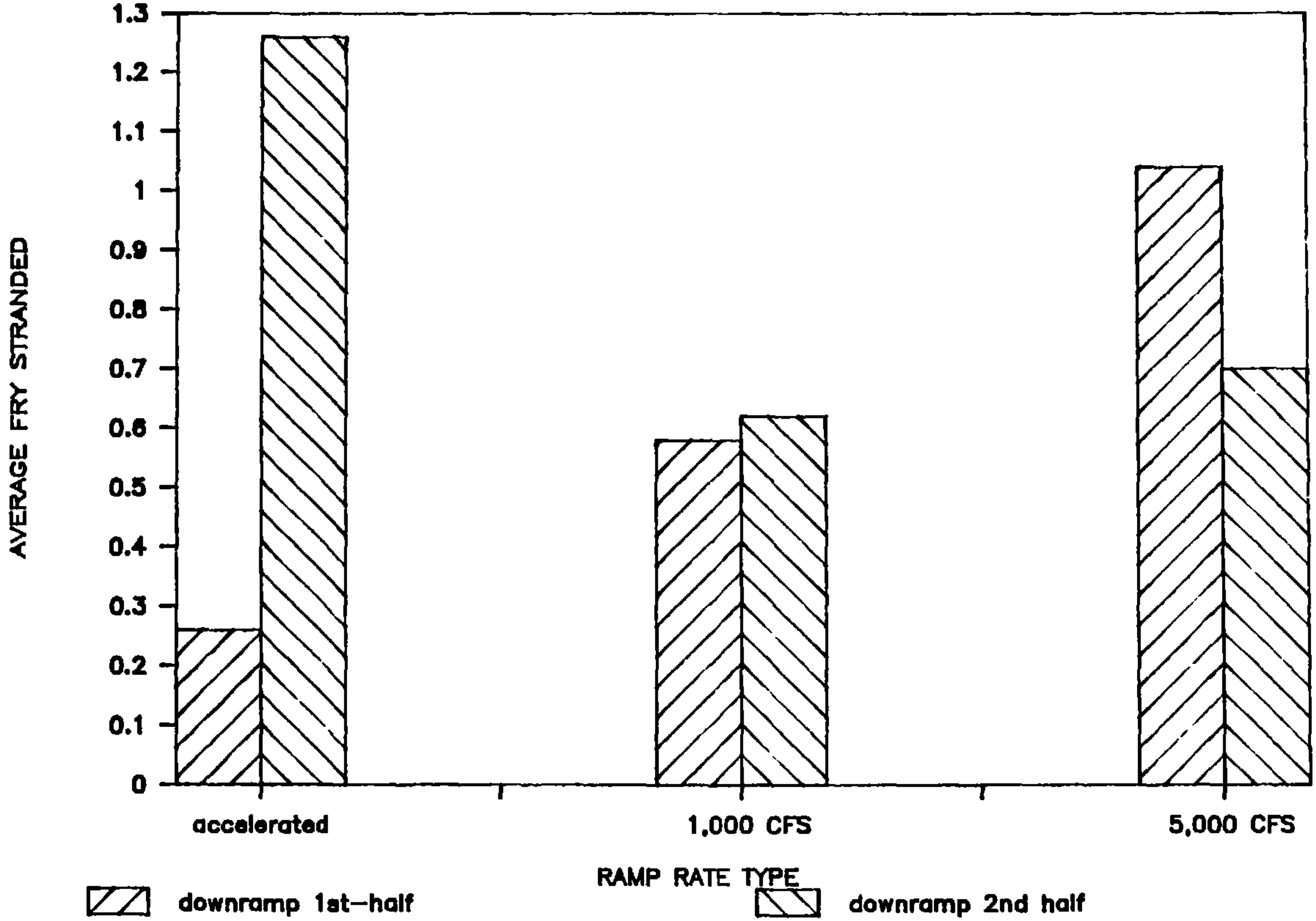


FIGURE 31

AVERAGE NUMBER OF STEELHEAD FRY STRANDED ON GRAVEL BARS DURING THE FIRST AND SECOND HALF OF 4000 CFS AMPLITUDE DOWNRAMP TESTS IN THE LOWER STUDY REACH



ramp rate below 1,000 cfs/hour, but above this level, the stranding rate does not increase with ramp rate up to at least 5,000 cfs, the highest observed ramp rate tested. It must be reemphasized that it can not be concluded from the study results that a 500 cfs/hour downramping rate is safer than a 1,000 cfs/hour ramping rate; however, the data suggests that this might be a possibility.

It is puzzling that the total number of fry stranded with accelerated and 5,000 cfs/hour tests are roughly the same since the 500 cfs/hour portion of the accelerated ramp rate killed far less fry. A possible explanation for this is that the fry that are not stranded during the 500-cfs/hour portion of the test move down into the area dewatered by the 5,000-cfs/hour portion of the test, which in effect, increases the fry density. A constant rate of stranding at 5,000 cfs/hour, with more fry at risk, means more fry stranded. Therefore, fry that escape stranding with a 500-cfs/hour ramp rate are ultimately stranded lower on the bar as a result of a fry density increase.

4. SIGNIFICANCE OF STEELHEAD/COHO FRY GRAVEL BAR STRANDING

Gravel bar stranding of salmonid fry has been documented by many fisheries' researchers over the years. Most of these studies had no quantitative means for determining the magnitude of gravel bar fry stranding impacts on the Skagit River. The intent of this study task was to develop a method of estimating the number of fry stranded on gravel bars between Newhalem and Rockport, given certain hydraulic conditions relating to the amplitude fluctuation of a downramp event, the downramp rate, and the river discharge level at the end of the downramp. The matrix that was developed for this purpose can be used to evaluate the magnitude and impact of gravel bar stranding on salmon fry in the spring and steelhead in the summer/fall.

A total of 42 gravel bar locations were identified in the study area, representing 29,110 lineal feet of gravel bar of various slope and substrate combinations (Table 22). Forty-seven percent of the total gravel bar within the study area is located within the 10.8 mile-long lower river reach, 19% in the middle reach, and 35% in the upper reach (Table 23).

TABLE 23

SUMMARY OF THE SKAGIT RIVER STUDY AREA
GRAVEL BAR INVENTORY

Study Reach	River Miles	Reach Length (miles)	Feet of Gravel Bar	Percent Of Total Gravel Bar
Lower River	67.5 - 78.2	10.8	13,600	46.7%
Middle River	78.3 - 84.1	5.9	5,400	18.6%
Upper River	84.2 - 92.9	8.8	10,110	34.7%
Totals		25.5	29,110	

TABLE 22

SKAGIT RIVER BAR INVENTORY DATA
FROM ROCKPORT TO GORGE POWERHOUSE

LOWER RIVER

	BAR NAME	BAR LOCATION (RIVER MILE)	SUBSTRATE TYPE (PRIMARY)	SLOPE (%)	BAR LENGTH (FEET)
1	ROCKPORT I IV	67.5	<3"	4	800
2	WAYNE SWIM I–III	68.1	<3"	3	600
3	WAYNE SWIM IV–VI	68.1	<3"	14	600
4	TIN SHACK I–IV	68.3	<3"	5	800
5	TIN SHACK V	68.3	<3"	12	200
6	TIN SHACK VI	68.3	<3"	4	200
7	BAD SPOT I	70.1	<3"	8	200
8	BAD SPOT II	70.1	<3"	6	200
9	BAD SPOT III	70.1	<3"	7	200
10	BAD SPOT IV	70.1	<3"	32	200
11	EAGLE BAR I–IV	70.1	<3"	4	800
12	EAGLE BAR V–VI	70.1	<3"	2	400
13	EAGLE BAR VII	70.1	<3"	11	200
14	EAGLE BAR VIII–X	70.1	>3"	7	600
15	FORBIDDEN BAR I–III	70.5	<3"	6	600
16	FORBIDDEN BAR IV–VI	70.5	<3"	5	600
17	J R BAR I–IV	71.1	>3"	6	800
18	STUMP HAVEN I–II	72.5	<3"	4	400
19	STUMP HAVEN III	72.5	<3"	18	200
20	MODEL I	72.6	>3"	7	200
21	MODEL II	72.6	>3"	9	200
22	HOOPER SLOUGH I–III	72.7	<3"	7	600
23	HOOPER SLOUGH IV–V	72.7	>3"	12	400
24	HOOPER SLOUGH VI–VII	72.7	<3"	38	400
25	INACCESSIBLE I	73.1	>3"	3	200
26	INACCESSIBLE II	73.1	>3"	5	200
27	INACCESSIBLE III	73.1	<3"	4	200
28	INACCESSIBLE IV	73.1	<3"	8	200
29	INACCESSIBLE V	73.1	<3"	17	200
30	CARNAGE BAR	73.3	<3"	7	200
31	POWER BAR I–III	74.2	<3"	4	600
32	DRY BAR	74.2	>3"	4	200
33	NORTH OBRIEN FERRY I	76.1	<3"	9	200
34	NORTH OBRIEN FERRY II	76.1	<3"	2	200
35	SECLUSION ISLAND	76.3	>3"	6	200
36	BIG EDDY I	77.5	>3"	9	200
37	BIG EDDY II	77.5	>3"	13	200
38	BIG EDDY III	77.5	>3"	17	200
				SUBTOTAL	13600

SKAGIT RIVER BAR INVENTORY DATA
FROM ROCKPORT TO GORGE POWERHOUSE

MIDDLE RIVER

	BAR NAME	BAR LOCATION (RIVER MILE)	SUBSTRATE TYPE (PRIMARY)	SLOPE (%)	BAR LENGTH (FEET)
39	MARBLEMOUNT BAR I	78.2	<3"	3	200
40	MARBLEMOUNT BAR II	78.2	<3"	2	200
41	MARBLEMOUNT BAR III	78.2	<3"	1	200
42	FUNGUS BAR I–II	78.5	>3"	2	400
43	FUNGUS BAR III	78.5	>3"	4	200
44	DIOBSUD I	80.6	<3"	13	200
45	DIOBSUD II	80.6	<3"	11	200
46	DIOBSUD III	80.6	>3"	9	200
47	DIOBSUD IV–V	80.6	<3"	5	400
48	SHOTGUN BAR I–III	81.5	<3"	7	600
49	MAPLE BAR	82.5	>3"	7	200
50	BACON BAR I–III	82.6	>3"	7	600
51	BACON BAR IV	82.6	<3"	13	200
52	FACE BAR I	82.7	<3"	5	200
53	FACE BAR II	82.7	<3"	14	200
54	FACE BAR III	82.7	>3"	32	200
55	OINK BAR I–II	82.9	<3"	6	400
56	OINK BAR III–IV	82.9	>3"	9	400
57	COPPER CREEK	84.1	>3"	19	200
				SUBTOTAL	5400

SKAGIT RIVER BAR INVENTORY DATA
FROM ROCKPORT TO GORGE POWERHOUSE

UPPER RIVER

BAR NAME	BAR LOCATION (RIVER MILE)	SUBSTRATE TYPE (PRIMARY)	SLOPE (%)	BAR LENGTH (FEET)
BAR 58	87.7	<3"	5	400
BAR 59A	87.8	>3"	10	850
BAR 59B	87.8	>3"	7	560
BAR 60A	88.5	<3"	12	500
BAR 60B	88.5	<3"	8	500
BAR 61	88.8	<3"	8	350
BAR 62	88.9	>3"	6	300
BAR 63	89.1	>3"	10	250
BAR 64	89.3	<3"	12	400
BAR 65	89.4	<3"	20	300
BAR 66	89.5	<3"	10	400
BAR 67A	90.1	>3"	11	500
BAR 67B	90.1	>3"	15	500
BAR 68	91.6	>3"	4	400
BAR 69	91.7	>3"	14	250
BAR 70A	91.9	<3"	13	450
BAR 70B	91.9	<3"	4	300
BAR 71A	92.1	>3"	21	600
BAR 71B	92.1	>3"	7	800
BAR 72	92.4	>3"	5	800
BAR 73A	92.9	<3"	18	350
BAR 73B	92.9	>3"	8	350
			SUBTOTAL	10110
			TOTAL GRAVEL BAR	29110

A detailed breakdown and distribution of bar types is shown on the right side of the matrix in Figure 32. The majority of the lower river is made up of bar slopes of less than 5% and substrate of less than 3 inches in diameter. The middle and upper river reaches show a more even distribution of the six different combinations of bar slope and substrate types.

The left side of the matrix shows the average number of steelhead fry stranded per 200 feet of gravel bar, given a specific combination of reach location, amplitude fluctuation, ramp rate, bar slope, and substrate. These data were derived from the results of the gravel bar stranding tests. Each value of average fry stranded in the matrix resulted from the summation of the total fry stranded divided by the total number of test replicates having a specific combination of the five variables listed above. The values representing the upper river reach from Newhalem to Copper Creek use the same values computed for the middle river reach.

The predictive matrix was developed to estimate the relative number of steelhead fry stranded on gravel bars within the 26-mile study area for six different downramping scenarios (Figure 33). Each cell of this matrix is the product of the average number of fry stranded/200 feet of gravel bar for that cell type and the number of 200 foot-long gravel bar units within each river reach. (See example in Figure 34). Each cell of the predictive matrix contains three individual numbers representing stranded steelhead fry for upper, middle, and lower river reaches. Each of the six columns in the matrix represents a different type of downramping scenario. The cumulative sum of each column is the prediction for the total number of stranded steelhead fry for the entire study area from Newhalem to Rockport. The lowest stranding total of 106.7 steelhead fry is for a 2,000 cfs downramp amplitude fluctuation and a 1,000-cfs/hour ramping rate. The highest stranding total, 622.6 steelhead fry, was predicted for a 4,000 cfs amplitude fluctuation and a ramp rate of 5,000 cfs/hour.

To determine the magnitude of the steelhead gravel bar stranding on the Skagit River from Newhalem to Rockport, these daily estimates must be applied to the period of peak vulnerability, which conservatively appears to be approximately 75 days (July 15 to September 30) in length. If the dam is operated over the entire 75-day period so that it strands the maximum number of fry per day (622.6), which is very unlikely, a total of 46,695 steelhead fry would be stranded during the peak vulnerability period. Before and after the peak vulnerability period, gravel bar stranding of steelhead would contribute little to this total since fry are presumably not present before this period and steelhead juveniles are much less vulnerable to stranding. The total stranded in a given year could and would vary depending on adult escapement, egg-to-fry survival, daily dam operation over the peak vulnerability period, and the type and amount of gravel bars which changes dynamically from year-to-year.

This relative estimate must be further qualified since it does not and could not make adjustments for several sources of error including observer error and predation on stranded fry. The relative estimate was developed within the limits of the study and does not reflect total stranding, but certainly accounts for a large portion of it.

FIGURE 32

MATRIX SHOWING THE AVERAGE NUMBER OF STRANDED STEELHEAD AND COHO FRY FOR 36 DIFFERENT COMBINATIONS OF GRAVEL BAR SLOPES, AND SUBSTRATE BY DOWNRAMP AMPLITUDE AND RAMPRATE IN ADDITION TO GRAVEL BAR REACH LOCATIONS AND LENGTHS. SUMMER 1985

GRAVEL BAR SLOPE (%)	PRIMARY SUBSTRATE SIZE (Inches)	DOWNRAMP AMPLITUDE 2000 cfs			DOWNRAMP AMPLITUDE 4000 cfs			GRAVEL BAR LOCATION AND LENGTH (Lineal Feet)		
		RAMPRATE (cfs/hour)			RAMPRATE (cfs/hour)					
		Accelerated(1)	1000	5000	Accelerated(1)	1000	5000	UPPER REACH	MIDDLE REACH	LOWER REACH
0-5%	<3"	U=3.0 M=3.0 L=8.0	U=3.0 M=3.0 L=1.0	U=1.9 M=1.9 L=0.9	U=9.8 M=9.8 L=5.3	U=3.7 M=3.7 L=4.4	U=17.3 M=17.3 L=4.3	700	1,200	5,800
	>3"	U=10.6 M=10.6 L=0.5	U=0.6 M=0.6 L=1.0	U=4.8 M=4.8 L=0.4	U=14.3 M=14.3 L=2.7	U=21.4 M=21.4 L=1.5	U=9.4 M=9.4 L=2.3	1,200	600	600
>5%-10%	<3"	U=0.9 M=0.9 L=0.0	U=1.9 M=1.9 L=0.3	U=2.5 M=2.5 L=0.4	U=12.2 M=12.2 L=0.7	U=5.1 M=5.1 L=1.4	U=11.2 M=11.2 L=1.1	1,200	1,000	2,400
	>3"	U=0.1 M=0.1 L=0.7	U=0.2 M=0.2 L=0.5	U=0.3 M=0.3 L=0.1	U=0.1 M=0.1 L=0.7	U=0.1 M=0.1 L=0.4	U=0.4 M=0.4 L=1.6	3,110	1,400	2,000
>10%	<3"	U=0.0 M=0.0 L=0.0	U=0.0 M=0.0 L=0.0	U=0.0 M=0.0 L=0.0	U=0.7 M=0.7 L=0.0	U=1.2 M=1.2 L=0.0	U=2.5 M=2.5 L=0.0	2,000	800	2,000
	>3"	U=1.3 M=1.3 L=0.1	U=0.5 M=0.5 L=0.3	U=1.3 M=1.3 L=0.1	U=3.7 (2) M=3.7 L=0.2	U=2.0 M=2.0 L=0.0	U=3.7 M=3.7 L=0.5	1,850 (2)	400	800

Upper Reach — U=3.7
Middle Reach — M=3.7
Lower Reach — L=0.2

AVERAGE NUMBER OF FRY STRANDED/200 FT OF GRAVEL BAR FOR DIFFERENT COMBINATIONS OF BAR SLOPE, SUBSTRATE, RAMPRATE, AND AMPLITUDE FLUCTUATION OF A DOWNRAMP EVENT (2)

(1). The Accelerated Downramp began with a ramprate of 500 cfs/hr followed by 5000 cfs/hr until the specified Amplitude Fluctuation was accomplished.

(2). See Figure 34 for typical method of calculation for each Stranding Prediction scenario.

FIGURE 33

MATRIX PREDICTING TOTAL STEELHEAD AND COHO FRY STRANDED WITHIN THE THREE REACH STUDY AREA FOR SIX DIFFERENT DOWNRAMP SCENARIOS. SUMMER 1985

GRAVEL BAR SLOPE (%)	PRIMARY SUBSTRATE SIZE (inches)	DOWNRAMP AMPLITUDE 2000 cfs			DOWNRAMP AMPLITUDE 4000 cfs		
		RAMPRATE (cfs/hour)			RAMPRATE (cfs/hour)		
		Accelerated(1)	1000	5000	Accelerated(1)	1000	5000
0-5%	<3"	U=10.5 M=18.0 L=232.0	U=10.5 M=18.0 L=29.0	U=8.7 M=11.4 L=26.1	U=34.3 M=58.8 L=153.7	U=13.0 M=22.2 L=127.8	U=60.8 M=103.8 L=124.7
	>3"	U=63.8 M=31.8 L=1.5	U=3.6 M=1.8 L=3 0	U=28.8 M=14.4 L=1.2	U=85.8 M=42.9 L=8.1	U=128.4' M=64.2 L=4.6	U=58.4 M=28.2 L=6.9
>5%-10%	<3"	U=5.4 M=4.5 L=0.0	U=11.4 M=9.5 L=3.6	U=15.0 M=12.5 L=4.8	U=73.2 M=61.0 L=8.4	U=30.6 M=25.5 L=16.8	U=67.2 M=56.0 L=13.2
	>3"	U=1.6 M=0.7 L=7.0	U=3.1 M=1.4 L=5.0	U=4.7 M=2.1 L=1.0	U=1 6 M=0.7 L=7.0	U=1.6 M=0.7 L=4.0	U=6.2 M=2.8 L=18.0
>10%	<3"	U=0.0 M=0.0 L=0.0	U=0.0 M=0.0 L=0.0	U=0.0 M=0.0 L=0.0	U=7.0 M=2.8 L=0.0	U=12.0 M=4.8 L=0.0	U=25.0 M=10.0 L=0.0
	>3"	U=12.0 M=2.6 L=0.4	U=4.6 M=1.0 L=1.2	U=12 0 M=2 6 L=0.4	U=34.2 (2) M=7.4 L=0.8	U=18.5 M=4.0 L=0.0	U=34.2 M=7.4 L=2.0
	TOTALS	359.8	106.7	131.7	587.7	478.4	622.6

(1). The Accelerated Downramp began with a ramprate of 500 cfs/hr followed by 5000 cfs/hr until the specified Amplitude Fluctuation was accomplished.

(2). See Figure 34 for typical method of calculation for each Stranding Prediction scenario.

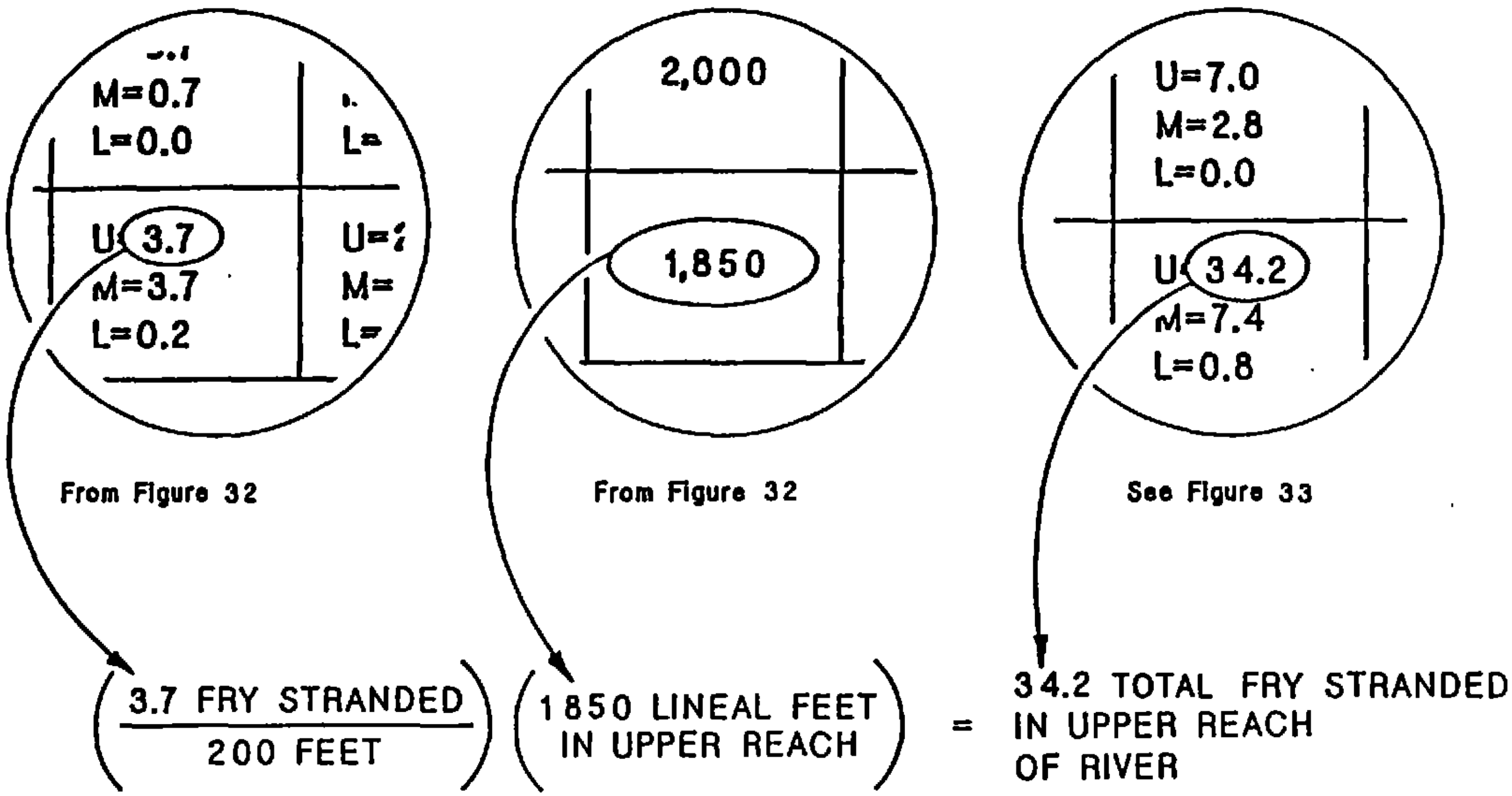
Upper Reach — U=12.0
Middle Reach — M=2.6
Lower Reach — L=0.4

} TOTAL FRY STRANDED DURING DOWNRAMP EVENT IN EACH RIVER REACH

478.4 } EQUALS PREDICTED NUMBER OF STRANDED FRY FOR ALL GRAVEL BARS IN THE STUDY AREA (COLUMN TOTAL) BY TEST TYPE

FIGURE 34

STRANDING PREDICTION
TYPICAL METHOD OF CALCULATION



5. OBSERVER ACCURACY TESTING

Gravel bar fry stranding tests have been conducted on the Skagit, Cowlitz, and Sultan Rivers in recent years. All of these studies required visual counts of fry stranded. The purpose of this experiment was to determine the accuracy of a typical observer attempting to locate fry stranded on a gravel bar of several different physical makeups. A determination of observer accuracy is extremely important to a quantitative study of this type. Observer accuracy was determined by comparing the number fry placed on a gravel bar in a visible position to the number of fry actually detected by an observer.

TABLE 24

STEELHEAD GRAVEL BAR STRANDING CONTROL TEST RESULTS

Test Number	Gravel Bar	Site Number	Live Planted	Dead Planted	Number Recovered	Substrate Type
1	Inaccessible Island	3	*5		1	large
2	Inaccessible Island	2	*5		0	large
3	Inaccessible Island	2		5	4	large
4	Rockport Bar	1		**6	4	small
5	Rockport Bar	2		**3	2	small
6	Rockport Bar	3		**7	2	small
7	Forbidden Bar	1		6	5	small
8	Forbidden Bar	2		5	5	small
9	Big Eddy	3		6	4	large
10	Bacon Creek	1		6	5	large

* Live fry placed on the gravel bar with a bucket of water quickly moved beneath rocks until water drained away. Many of these fry stayed beneath these rocks making it impossible for observer to find these fry.

** These control tests were conducted at approximately 1 pm on a very hot, dry day. All fry desiccated quickly when placed on the gravel bar and became very unrealistic looking and difficult to locate by observers.

TABLE 25

SUMMARY OF GRAVEL BAR STRANDING CONTROL TESTS

Test Type	Fry Planted	Fry Found	Percentage Recovered
Live Fry	10	1	10%
Dead Fry (cumulative)	28	23	82%
Dead Fry - Large Substrate	17	13	76%
Dead Fry - Small Substrate	11	10	91%
Dead Fry - Sunny/PM Tests	16	8	50%

(1) Live Fry Tests

Two live fry control tests were conducted on gravel bars with large substrate (Table 24). The objective of the control testing was to determine what percentage of the visible stranded fry an observer would typically locate. In both cases most of the fry remained under rocks after bucket-water used to introduce them to the bar had drained away. This appeared to create an abnormal stranding situation due to fry panic when released from the bucket and also made it impossible for an observer to find the fry since they typically were not visible to the human eye. Since live fry did not always stay visible, they could not be used.

Prior to conducting live fry control tests we released several bunches of fry in one location on a typical gravel bar to observe fry stranding behavior. When released, these fry had several minutes to move around among the substrate before the water from the bucket began to drain into the gravel. When first released, most fry immediately moved beneath the nearest or best cover source. Once the bucket water had drained from the immediate release site the fry began to struggle. Most of the stranded fry continued to struggle for several minutes and the ones located under cover remained there even after several minutes of flopping about after the water had drained from the site. Some of the fry eventually were able to work their way out from underneath the cover, but this was purely a random result of their struggle. The results of these two tests indicate that observer accuracy could not be determined because a large number of the released fry moved under cover and never reappeared. This is supported by the results of the two live fry tests in which only 10% of the released fry were recovered by the observer being tested (Table 25). Typically, the undetected fry could not be relocated after the test had been completed, demonstrating the fry's ability to conceal themselves after being released with water from a bucket.

(2) <u>Dead Fry Tests</u>

Several different types of observer accuracy tests were conducted once it was determined that control tests required dead fry to produce a more ideal situation. The first tests were conducted by placing fry on the gravel bar in the early morning hours before sunlight reached the bar so that fry did not become desiccated and abnormal in appearance. A total of five tests of this type were completed, three of which involved bars with large (greater than 3 inch) substrate, and two other tests on bars with small substrate (Table 24). In each case the exact coordinates of the fry placed on the bar were documented so that undetected fry could be relocated to reconfirm their visibility and presence. Furthermore, if a naturally stranded fry were found by the observer, its coordinates could be compared with those of the control test fry so that these fry could be eliminated from the results of the control test.

The three tests conducted on large substrate indicated that 76% of the planted fry were recovered and two additional tests with small substrate had a 91% recovery rate (Table 25). These results appear to support the thought that as the gravel bar substrate complexity increases, the observer accuracy is reduced, but that recovery rates were generally high. These tests were conducted to simulate observer accuracy on a strictly qualitative basis and by no means should be interpreted otherwise. The purpose was merely to qualitatively understand whether a typical observer is finding some, most, or virtually all of the visible fry stranded on a given bar and at the same time evaluate whether substrate complexity has an effect on accuracy.

Three additional dead fry tests were conducted in the afternoon after the observer had finished locating fry for that day's tests. Fry were placed on the bar in an identical manner to those described above with the noted exception of time of day and weather. These tests took place in the afternoon of a very hot summer day. Fry used in these tests were quickly desiccated and became very difficult to see. The observers were able to locate 50% of the fry placed on the bar. This is considerably lower than the recovery rates from the morning control tests. The lower recovery rate is due to the poor condition of the fry resulting from desiccation. These results perhaps emphasize the importance of searching bars as early as possible to avoid fry desiccation or removal by scavengers such as birds.

SECTION VI

RESULTS OF SPRING 1986 GRAVEL BAR STRANDING STUDIES

1. BIOLOGICAL FACTORS AFFECTING FRY VULNERABILITY TO GRAVEL BAR STRANDING

Gravel bar stranding of salmonid fry is dependent on the fry being present and, when present, occupying gravel bar habitat dewatered by downramp events. There were four salmonid species; chinook, chum, pink, and steelhead present in the Skagit River during the field portion of these studies. Every other year (odd years) pink salmon return to the Skagit River to spawn. Pink salmon that spawned in the fall of 1985 produced emerging fry in the spring of 1986 that were exposed to gravel bar stranding. Following emergence, pink fry move quickly downstream toward saltwater and, as such, are vulnerable to gravel bar stranding for only a short time. Chum salmon fry resulting from fall spawning adults, like pink fry, spend only a short amount of time in the upper Skagit River on their way to saltwater. Chum, unlike pink salmon, spawn every year. Chinook salmon also spawn every year in the fall, and their fry emerge in the spring months and are vulnerable to gravel bar stranding since the fry rear in the Skagit River for some time after emergence (typically 90 days). Steelhead juveniles are also present in the spring months, having over-wintered after emergence in the previous summer/fall (typically between July and August). When the term "salmon fry" is used in this report, it refers to all four of the aforementioned fry species unless otherwise specified. A summary of all the data collected for the 1986 Spring Gravel Bar Stranding Study is found in Appendix N of this report.

a. Vulnerability of Specific Species

A total of 513 salmon fry and steelhead juveniles were found stranded on gravel bars during the 23 formal gravel bar stranding tests that were conducted between March 14 and April 13, 1986 (Table 26). With the exception of 16 fish, all were identified by species. Nearly 63% of the fish stranded during this period were chinook fry, 30% were made up of pink fry, with chum fry and steelhead juveniles representing 5.0 and 2.2% respectively (Tables 26 and 27).

It is clear from these data that all three salmon fry species and steelhead juveniles are susceptible to gravel bar stranding but it also appears that some are more vulnerable than others. Chinook and pink salmon fry were stranded in much higher numbers than chum and steelhead fry. This is understandable for chinook since the fry density of this species is so much higher than any other in main-channel habitat (Figure 35). Chinook accounted for 81% of the main-channel fry population and only 42.9% of the stranded fry in late March and 77% in early April (Figures 36 and 37.) Pink salmon, in contrast, made-up only 8.8% of the main-channel population in late March compared to 45.4% of the stranded population for that same time period. In early April, pink fry accounted for a much smaller portion of the main-channel population at 1.7% but still accounted for nearly 19% of the fry stranded.

TABLE 26

SKAGIT RIVER SALMON FRY AND STEELHEAD JUVENILE DATA FOR DIFFERENT CAPTURE LOCATION TYPES AND TIME PERIODS BETWEEN MARCH 14 AND APRIL 13, 1986

SPECIES	CAPTURE LOCATION TYPE	TIME INTERVAL	FISH NUMBER	AVERAGE LENGTH (cm)	LENGTH RANGE (cm)	STANDARD DEVIATION	VARIANCE
CHINOOK	Gravel Bar Stranded	March 14 - 31 April 1 - 14	82 220	4.38 4.38	3.5 - 5.8 3.8 - 4.8	0.280 0.180	0.080 0.03
	Main Channel (Electroshocked)	March 14 - 26 April 2 - 13	202 486	4.36 4.3	3.1 - 5.6 3.4 - 5.0	0.239 0.180	0.057 0.038
	Potholes (Electroshocked)	March 14 - 26 April 2 - 13	180 105	4.51 4.26	3.6 - 12.0 3.2 - 4.9	0.638 0.229	0.407 0.052
	Back Channels (Electroshocked)	March 14 - 26 April 2 - 13	158 253	4.49 4.41	3.8 - 6.0 3.8 - 5.3	0.580 0.230	0.34 0.054
CHUM	Gravel Bar Stranded	March 14 - 31 April 1 - 14	20 5	4.35 4.1	3.9 - 4.8 3.7 - 4.6	0.230 0.320	0.050 0.10
	Main Channel (Electroshocked)	March 14 - 26 April 2 - 13	1 5	3.9 4.26	n/a 4.2 - 4.4	n/a 0.080	n/a 0.006
	Potholes (Electroshocked)	March 14 - 26 April 2 - 13	0 0	n/a n/a	n/a n/a	n/a n/a	n/a n/a
	Back Channels (Electroshocked)	March 14 - 26 April 2 - 13	3 1	3.8 4.2	3.7 - 3.9 n/a	0.080 n/a	0.006 n/a
PINK	Gravel Bar Stranded	March 14 - 31 April 1 - 14	87 52	3.39 3.47	2.4 - 4.2 3.1 - 3.8	0.270 0.180	0.07 0.03
	Main Channel (Electroshocked)	March 14 - 26 April 2 - 13	22 9	3.38 3.41	3.1 - 3.6 3.1 - 3.7	0.140 0.200	0.019 0.04
	Potholes (Electroshocked)	March 14 - 26 April 2 - 13	7 0	3.4 n/a	3.2 - 3.8 n/a	0.130 n/a	0.017 n/a
	Back Channels (Electroshocked)	March 14 - 26 April 2 - 13	19 0	3.5 n/a	3.1 - 3.8 n/a	0.112 n/a	0.012 n/a
STEELHEAD	Gravel Bar Stranded	March 14 - 31 April 1 - 14	5 6	5.88 6.63	4.9 - 7.1 5.8 - 7.8	0.810 0.610	0.66 0.38
	Main Channel (Electroshocked)	March 14 - 26 April 2 - 13	25 23	6.32 6.41	4.7 - 7.7 4.7 - 8.7	0.750 0.980	0.570 0.97
	Potholes (Electroshocked)	March 14 - 26 April 2 - 13	6 4	6.05 6.2	4.6 - 8.2 4.8 - 7.5	1.230 0.970	1.51 0.950
	Back Channels (Electroshocked)	March 14 - 26 April 2 - 13	27 16	5.63 5.53	3.9 - 10.5 4.5 - 6.8	1.170 0.630	1.13 0.39

n/a = Not Applicable

FIGURE 35

SPECIES COMPOSITION OF FRY ELECTROSHOCKED FROM THREE DIFFERENT HABITAT TYPES VERSUS THOSE STRANDED ON GRAVEL BARS EXPRESSED AS A PERCENTAGE OF THE POPULATION SAMPLED DURING THE SPRING 1986 GRAVEL BAR STRANDING STUDY

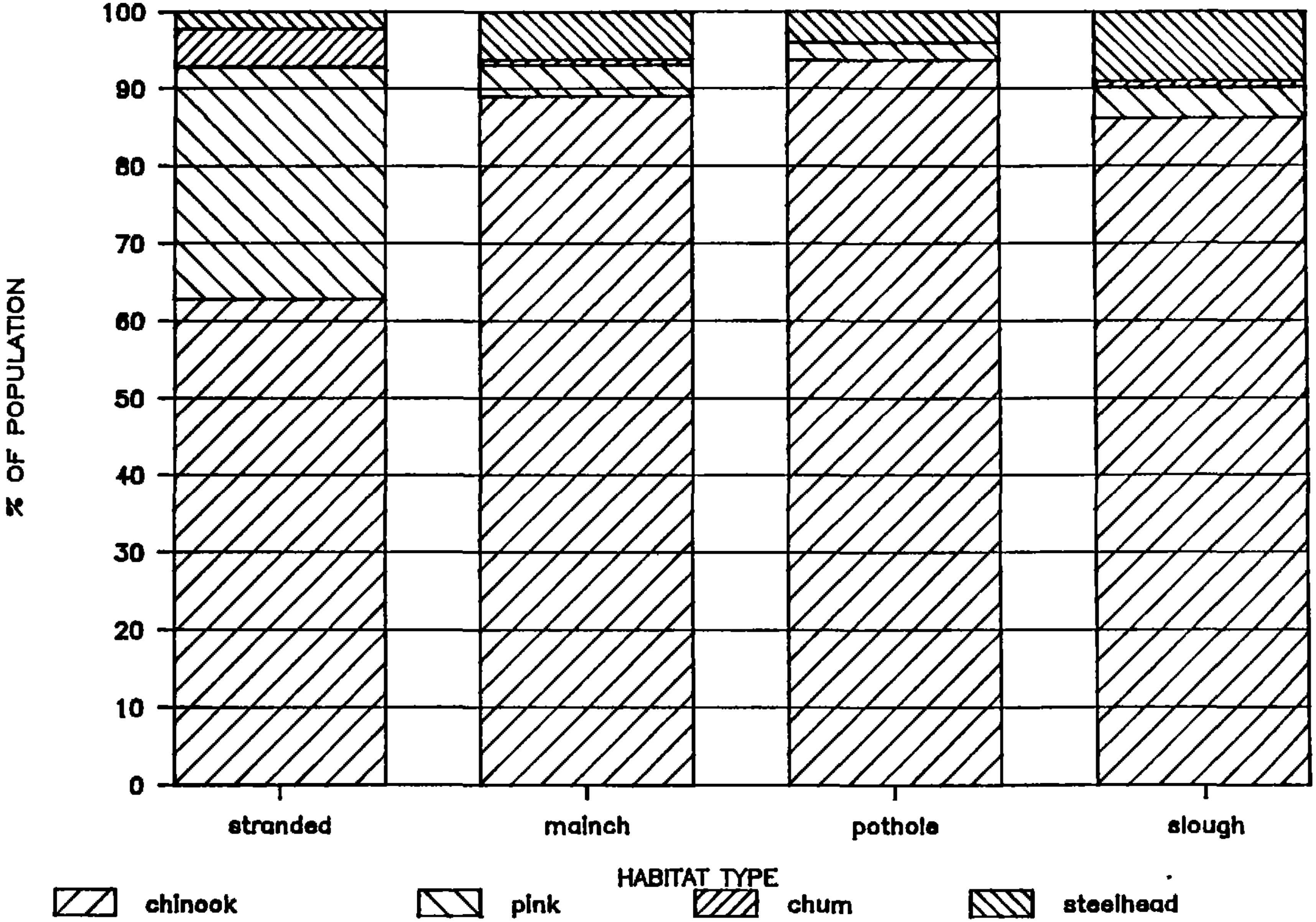


FIGURE 36

COMPARISON OF GRAVEL BAR STRANDED AND ELECTROSHOCKED MAINCHANNEL HABITAT FRY POPULATIONS EXPRESSED AS A PERCENTAGE OF TOTAL FRY IN EACH POPULATION DURING MARCH 13-27

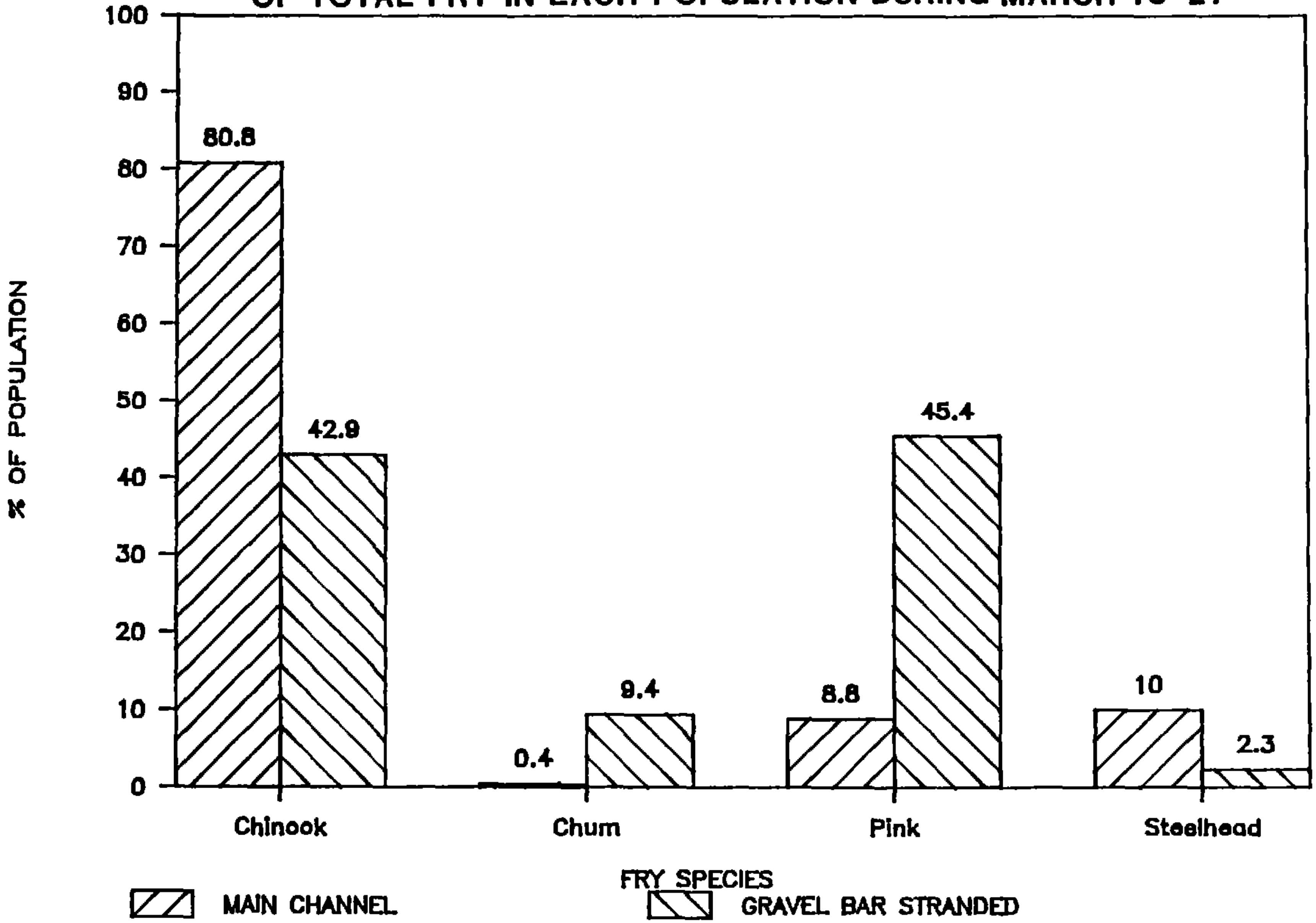


FIGURE 37

COMPARISON OF GRAVEL BAR STRANDED AND ELECTROSHOCKED MAINCHANNEL HABITAT FRY POPULATIONS EXPRESSED AS A PERCENTAGE OF TOTAL FRY IN EACH POPULATION DURING APRIL 1-14

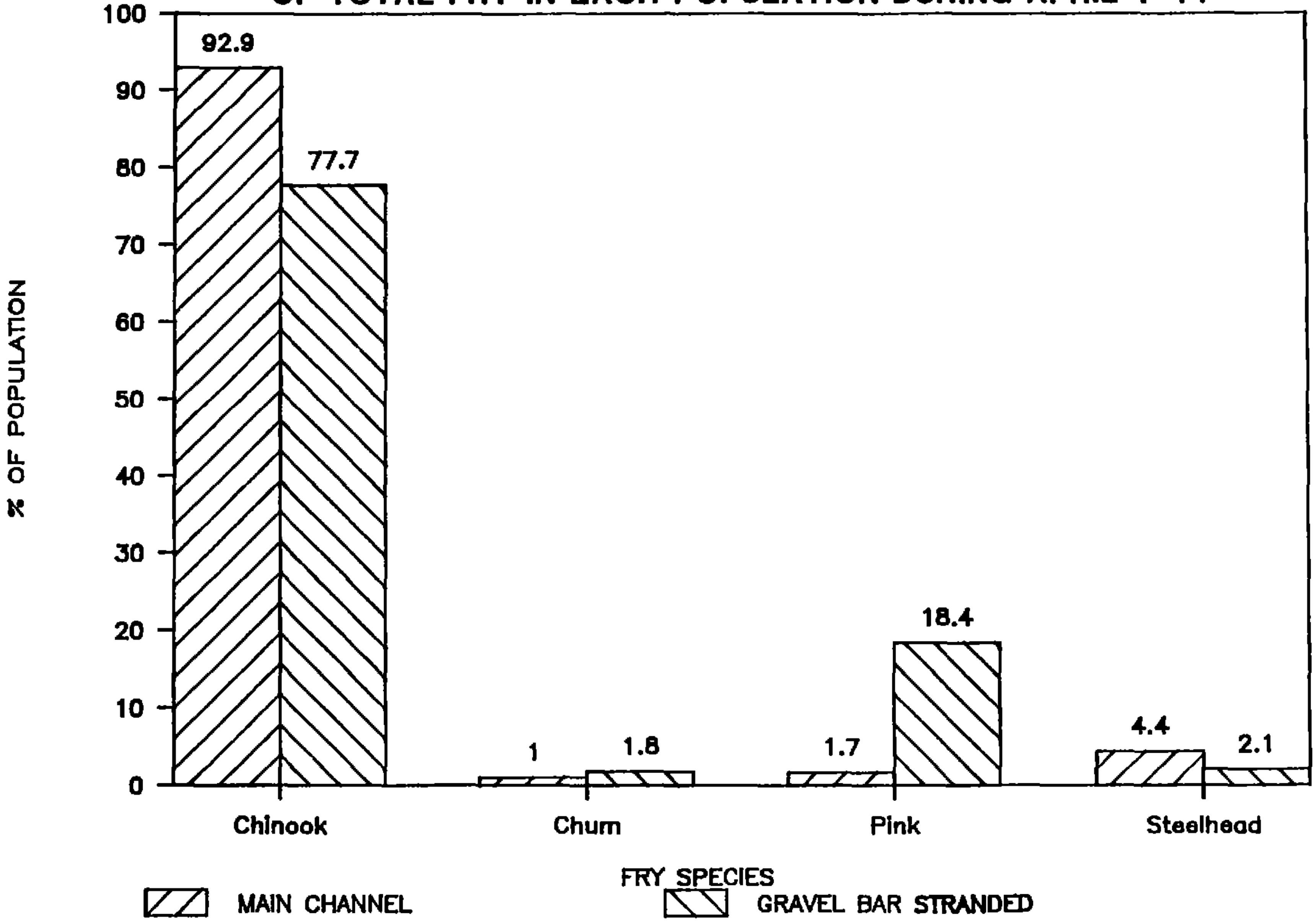


TABLE 27

SPECIES COMPOSITION OF THE GRAVEL BAR STRANDED FRY
DURING LATE MARCH AND EARLY APRIL
RESULTING FROM 23 DAYS OF GRAVEL BAR STRANDING TESTS

Fry Species	Stranded Fry						Total Fry Nos.
	March 14-26		April 1-13		March 14 - April 13		
	#'s	%	#'s	%	#'s	%	
Chinook	92	42.9	220	77.7	312	62.8	624
Chum	20	9.4	5	1.8	25	5.0	50
Pink	97	45.4	52	18.4	149	30.0	298
Steelhead ..	5	2.3	6	2.1	11	2.2	22
Total Fry Nos.	214		283		497		994

Similarly, chum fry in late March represent only 0.4% of the main-channel fry population but account for nearly 10% of the fry stranded. The obvious conclusion is that chum fry, like pink, appear to be much more vulnerable to gravel bar stranding when they are present in gravel bar habitat. Very few steelhead juveniles were stranded on gravel bars as might be expected by the results of the summer/fall steelhead gravel bar stranding study in Section IV of this report. The larger steelhead fry and juveniles become, the less likely they are to become stranded on gravel bars. This was identified by the data in Figures 36 and 37, which show that the percentage of the main-channel steelhead juvenile population is always much higher than the corresponding stranded percentages.

The data suggests that pink and chum fry are more vulnerable to gravel bar stranding than chinook fry, which in turn are more susceptible than steelhead juveniles. Because chinook fry are so much more abundant, higher numbers are stranded even though their rate of stranding is lower than either pink or chum fry. When pink fry are not present (every other year) in the Skagit River, 89.7% of the fry stranded will be chinook, 7.2% chum, and 3.1% steelhead. This can be derived by eliminating the pink salmon fry shown as stranded in Table 27.

The vulnerability of each species can be derived using the following relationship, which estimates the rate of stranding for each species relative to chinook fry:

Where: Rc = stranding rate of chinook fry
Rp = stranding rate of pink fry
Sc = number of chinook fry stranded on gravel bars
Sp = number of pink fry stranded on gravel bars
Mc = number of chinook fry in main-channel habitat
Mp = number of pink fry in main-channel habitat
ch = chinook
p = pink
c = chum
s = steelhead
Vp/s = relative stranding rate of pink fry

For example, the following estimates the rate of stranding for pink salmon fry relative to chinook fry during the March 14-26 time period:

$$Vp/s = \frac{97 \times 202}{92 \times 22} = 9.68$$

which roughly means that pink fry are approximately 10 times more vulnerable to gravel bar stranding than chinook fry.

The following table gives the relative vulnerability results for all species during both the late March and early April time periods.

The results of Table 28, which predict stranding rates relative to chinook fry indicate that pink fry, when present, are 10-13 times more vulnerable to gravel bar stranding than chinook fry. Chum fry are also highly susceptible to gravel bar stranding; at least 2-43 times more vulnerable than chinook. Steelhead juveniles, as expected from the results in Section V, are less vulnerable to gravel bar stranding than chinook fry.

TABLE 28

PREDICTED STRANDING RATES FOR PINK, CHUM FRY
AND JUVENILE STEELHEAD FOR TWO TIME PERIODS
IN MARCH AND APRIL RELATIVE TO CHINOOK FRY VULNERABILITY

Species	Stranding Rates March 14-26	Stranding Rates April 2-13
Chinook Fry	1.0	1.0
Pink Fry	12.8	10.0
Chum Fry	43.5	2.2
Steelhead Juvenile	0.4	0.6

All four species of salmonids found in main-channel habitat of the Skagit River were found stranded on gravel bars. Each species contributed varying amounts to the total of 513 fry stranded. The species contribution to total stranding is a function of fry abundance and rate of stranding. Chinook contributed the most to the total stranded because of their high abundance even though they have a relatively low stranding rate. Behind chinook, pink salmon fry stranded the second highest number of fry during the study period. Pink were much less abundant than chinook, but because they are 10-13 times more vulnerable to stranding than chinook fry they were able to strand a higher number of fry during the late March portion of the testing period. Their abundance declined during early April, which resulted in a smaller percent contribution to the total stranded in April. Chum fry represented only 0.4% of the main-channel population in March, but had an extremely high stranding rate which explains why this species was able to contribute nearly 10% to the total stranded in March. Steelhead juveniles were two (2) times less susceptible to stranding than chinook and did not represent a high percentage of the main-channel population, which resulted in a small contribution to the total stranded during the testing period of approximately 2%.

b. Window of Vulnerability

Two different approaches can be used to define the gravel bar stranding window of vulnerability. The window of vulnerability is described as a time period where a specific fry species is most vulnerable to the effects of downramping. Fry presence and abundance in conjunction with fry length are two factors capable of defining the window of vulnerability. Fry of a particular species can only be affected by downramping when they are present in habitat that is dewatered. Secondly, when present, a fry species may only be vulnerable to gravel bar stranding during a specific, size related life-stage. To determine if gravel bar stranding of chinook, pink, and chum is size dependent, the "population" of fry occupying main-channel gravel bar habitat had to be compared to the "population" of fry actually being stranded on the gravel bars over time (steelhead are discussed in Section V of this report). This was accomplished by routinely electroshocking main-channel gravel bar habitat throughout the course of the study and comparing the species composition and length frequency distributions with the "population" of fry stranded on gravel bars. If no size dependency exists, the fry stranded on gravel bars will closely resemble the species composition and length frequency of fry residing in main-channel habitat.

Typically, chinook fry are present in the Skagit River from February though May (Table 29). Fry begin to emerge from gravel in February and most remain in the study area into late May before outmigrating to saltwater. Chum begin to appear in low numbers in February, with peak emergence occurring in April in most years. Upon emergence, they move downstream to saltwater as do pink salmon fry. Steelhead observed in spring are juveniles that have over-wintered. Steelhead fry are present from July though October. The small number of steelhead juveniles found stranded on gravel bars during the spring of 1986 were all much larger than the peak size of vulnerability discussed in Section V of this report and, for that reason, are thought to be well past the peak vulnerability period.

TABLE 29

TYPICAL FRY AND JUVENILE LIFE-STAGE TIMING FOR CHINOOK, CHUM, PINK AND STEELHEAD IN THE SKAGIT RIVER

Species	Fry Life-Stage Timing (months)
Chinook	February - May
Chum	February - May
Pink	February - May
Steelhead	July - October (fry)
	Year Round (Juveniles)

(1) Chinook

Peak abundance levels typically occur between February and May. The average size of stranded chinook fry , 4.3 cm, did not change between late March and early April and was identical to the average size of the population in the main-channel habitat (Figure 38, Table 30). Length frequency distribution comparisons between stranded and main-channel populations were almost identical (Figure 39, Table 30). These results indicate that no gravel bar stranding size dependency relationship applies to chinook; in fact, it appears that chinook fry move downstream before any appreciable growth is observed. It is reasonable to speculate that chinook fry moving downstream (out of study area) are replaced by newly emerging fry so that growth within the "population" was not detected during the one-month study period. It appears that chinook are equally vulnerable to gravel bar stranding during the majority of their freshwater life stage regardless of fry size.

(2) Pink and Chum

Peak abundance of pink salmon fry typically occurs in March and declines in April and May (Table 29). Chum abundance is typically highest in April and declines in May. Pink and chum fry outmigrate quickly, so they do not achieve any appreciable growth while in the study area (Figures 40 and 41). For this reason, no possible gravel bar stranding fry size dependency can exist. Their window of vulnerability is controlled by their presence in the study area from February to April every other year.

2. PHYSICAL AND HYDRAULIC FACTORS AFFECTING GRAVEL BAR STRANDING

As was the case for the 1985 analysis, the dependent variable (the number of fish stranded) was transformed using the natural logarithm of one plus the actual count, prior to performing analysis of variance (ANOVA) tests.

TABLE 30

LENGTH DISTRIBUTION OF CHINOOK SALMON FRY STRANDED ON GRAVEL BARS AND ELECTROSHOCKED FROM MAIN CHANNEL HABITAT EXPRESSED AS A PERCENTAGE OF THE RESPECTIVE SAMPLE SIZE

(Data collected from March 13 to April 26, 1988)

FRY SIZE (cm)	GRAVEL BAR STRANDED CHINOOK FRY DISTRIBUTION (% OF POPULATION)		MAIN CHANNEL ELECTROSHOCKED CHINOOK FRY DISTRIBUTION (% OF POPULATION)	
	MARCH 13 - APRIL 1	APRIL 2 - 26	MARCH 13 - APRIL 1	APRIL 2 - 26
0.0 - 0.5				
0.5 - 1.0				
1.0 - 1.5				
1.5 - 2.0				
2.0 - 2.5				
2.5 - 3.0				
3.0 - 3.5	2		1	0.2
3.5 - 4.0	5	6	6	8
4.0 - 4.5	69	81	80	83
4.5 - 5.0	23	13	12	8.8
5.0 - 5.5	1			
5.5 - 6.0			1	

FIGURE 38

COMPARISON OF GRAVEL BAR STRANDED CHINOOK SALMON FRY LENGTH FREQUENCIES FOR TWO SAMPLING PERIODS IN MARCH AND APRIL 1986

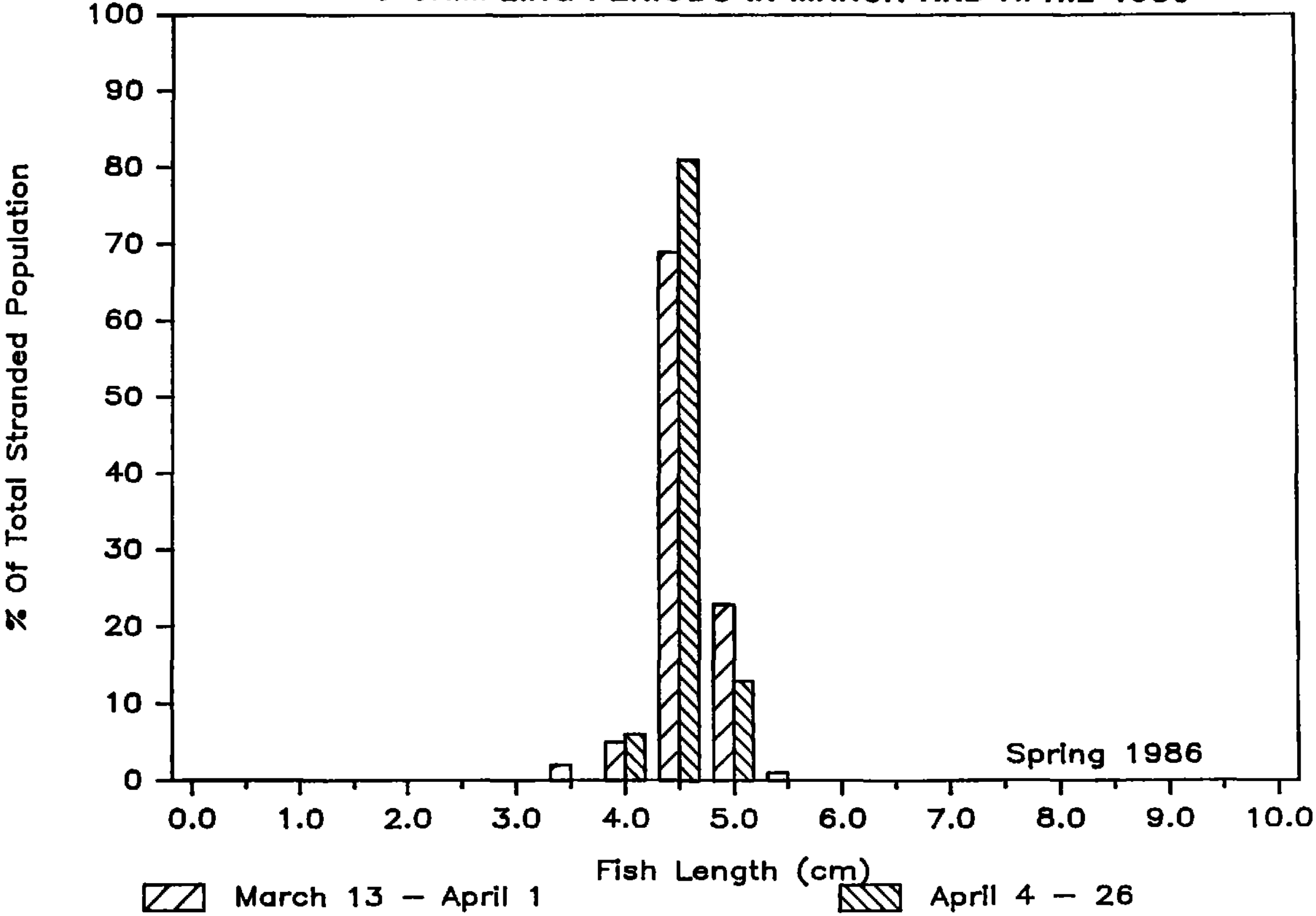


FIGURE 39

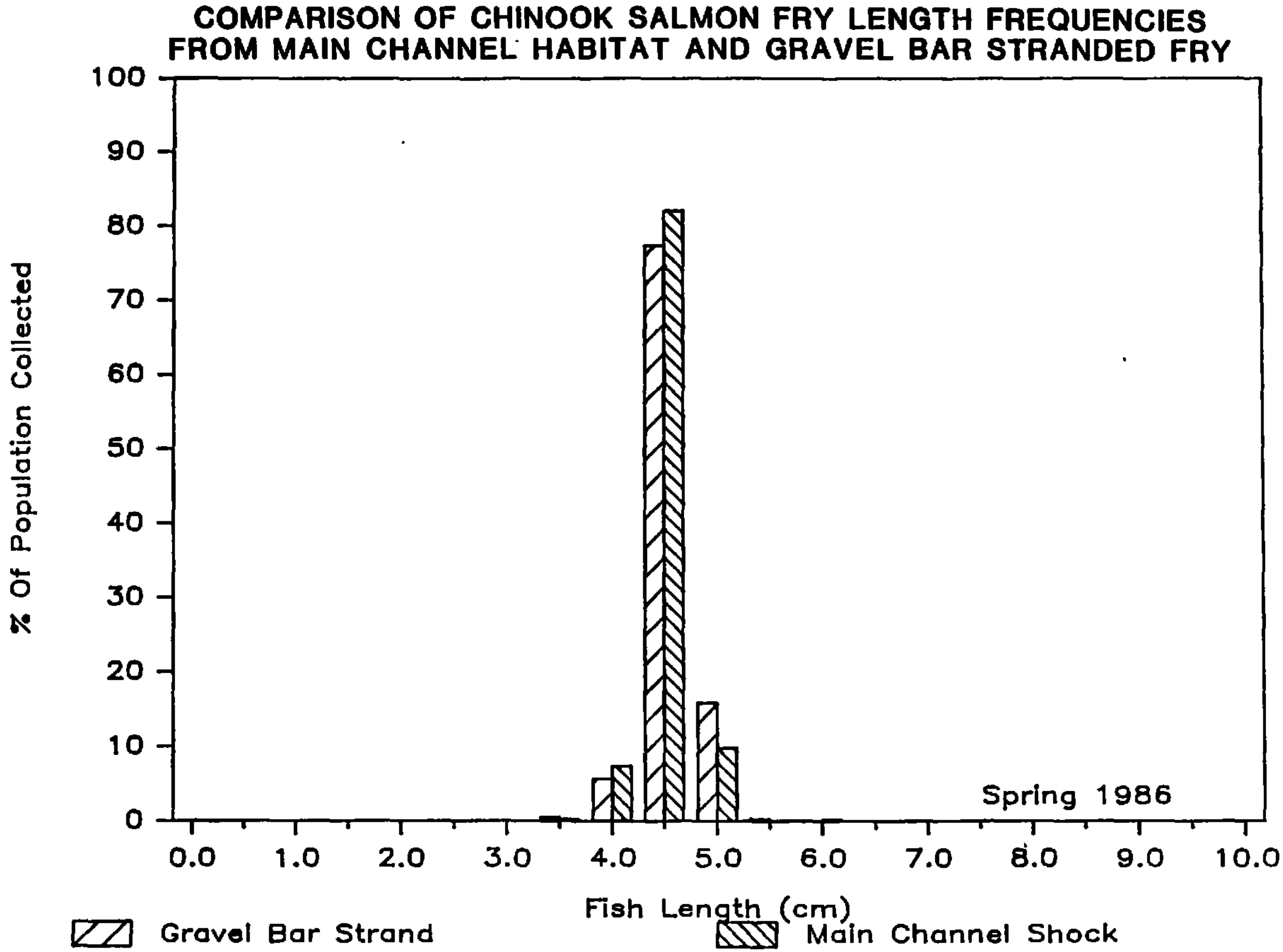

COMPARISON OF CHINOOK SALMON FRY LENGTH FREQUENCIES
FROM MAIN CHANNEL HABITAT AND GRAVEL BAR STRANDED FRY
% Of Population Collected
100
90
80
70
60
50
40
30
20
10
0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
Fish Length (cm)
Spring 1986
Gravel Bar Strand
Main Channel Shock

FIGURE 40

COMPARISON OF GRAVEL BAR STRANDED PINK SALMON FRY LENGTH FREQUENCIES FOR TWO DIFFERENT TIME PERIODS IN MARCH AND APRIL, 1986

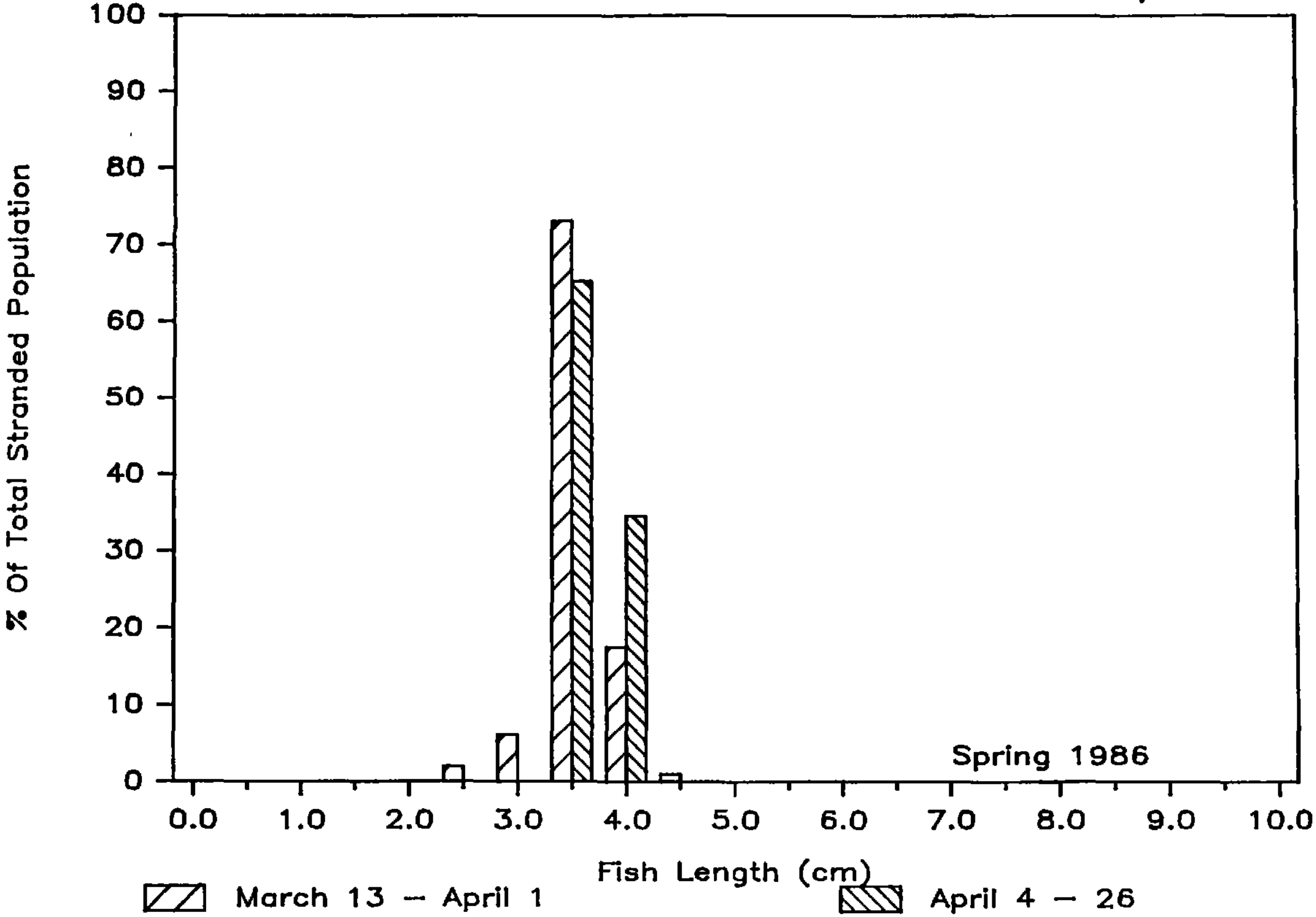
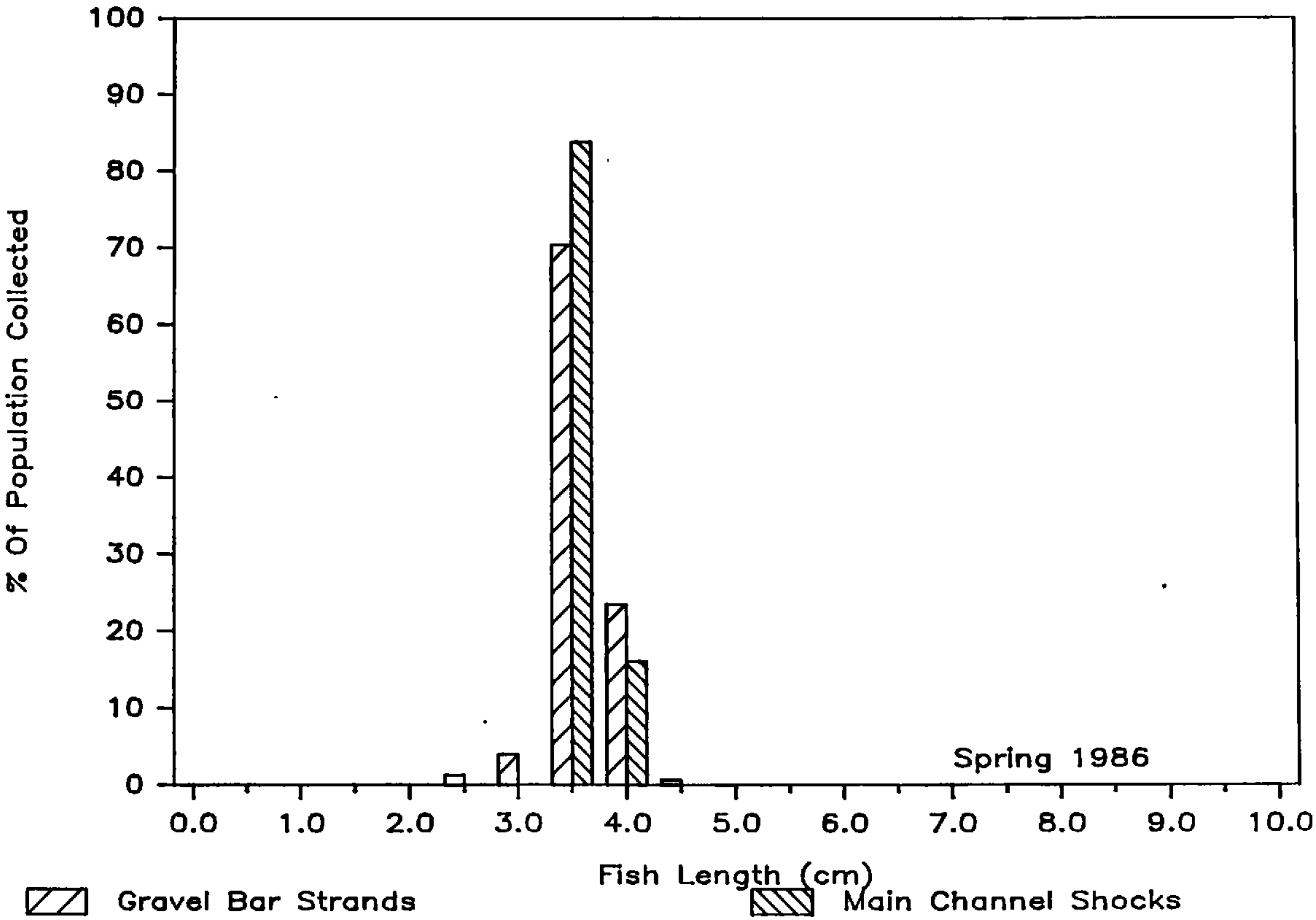


FIGURE 41

COMPARISON OF PINK SALMON FRY LENGTH FREQUENCIES FROM MAIN CHANNEL HABITAT AND GRAVEL BAR STRANDED FRY



The logarithmic transformation was used since the raw data showed proportionality between mean and standard deviation. There were 24 observations made on each of 35 gravel bar sites (Figures 4 and 5, Section III). For the twelve A1 (2,000 cfs amplitude downramp) events, each observation consisted of the total count of stranded fry. Thus 420 (12x35) measurements were obtained. For the twelve A2 (4,000 cfs of amplitude) events, two measurements were taken. Stranding observations at A2 events are bivariate, composed of the fry counts during the first and second half of the downramp event. The A2 events produce 12x35=420 paired observations.

In the initial analysis of variance (ANOVA), the two counts for each A2 event were added together and ANOVA's were performed separately for A1 and A2 observations for middle river (RIVLOC=1) and lower river (RIVLOC=2). The four ANOVA tables are shown in Tables 31-34. Cell means and standard deviation are listed in Appendix O.

Ending flow did not significantly affect stranding in any of the four tests and week number was significant only in the lower river during high amplitude events. We conclude that end flow in the range of 3,000 to 3,500 cfs as measured near Marblemount, does not significantly affect chinook fry stranding. The observations are balanced with respect to both week number and end flow and since the effects of week number is of minor importance the observations were pooled over these factors in the remaining analysis.

An ANOVA was performed using all 840 observations with two levels for each of the factors; amplitude, river location, substrate and ramping rate and three levels of slope. The result of this analysis is shown in Table 35, cell means and standard deviation can be found in Appendix O. There are several significant interactions identified in Table 35. Several of these involve river location and are very likely due to a preponderance of zero fry stranding observations. (See Appendix P, Table P-1.) The cell means in Appendix O and Figures 42-46 are useful in interpreting these interactions.

Numerous parametric and non-parametric tests were performed on subsets of the data producing results that were generally consistent with the ANOVA tables included here. The fact that a large portion of the stranding counts were zero may have had some effect on the study outcome in terms of biased counts, etc., and may also have affected the analytical results. However, it is important to bear in mind that the general conclusions stated in the following sections were as a rule upheld when subsets of the data containing few zeros were analyzed. Exceptions to this rule are noted in the discussions that follow. Cell means for untransformed observations are given in Appendix O.

An expected highly significant effect due to slope was confirmed. In fact, the average number of fry stranded on slopes less than 5% was more than 8 times greater than the average for the remaining observations (Figure 42). Coupled with the additional fact that 35% of the gravel bars in the study area have slopes less than 5%, leads to the conclusion that these bars may be responsible for as much as 80% of all salmon fry stranding. The following discussion summarizes the results of the statistical analysis for each factor separately.

Table 31 Analysis Of Variance For The 1986 Salmon Fry Stranding Study From The Middle Reach With 2,000 CFS Amplitude

Analysis of Variance   Dependent variable: LOGNUM
For the subgroup: RIVLOC = 1   A = 1

Source	df	SS (H)	MSS	F	P
Between Subjects	215	43.6130			
S (S)	2	8.0062	4.0031	28.231	0.0000
G (SUBSTR)	1	0.0385	0.0385	0.272	0.6030
W (WEEKN)	2	0.0380	0.0190	0.134	0.8755
E (E)	1	0.0360	0.0360	0.254	0.6152
R (R)	1	0.0190	0.0190	0.134	0.7146
SG	2	0.7081	0.3541	2.497	0.0853
SW	4	0.2946	0.0737	0.519	0.7236
SE	2	0.1151	0.0575	0.406	0.6696
SR	2	2.0066	1.0034	7.075	0.0012
GW	2	0.0606	0.0303	0.214	0.8094
GE	1	0.0018	0.0018	0.013	0.9095
GR	1	0.0071	0.0071	0.050	0.8227
WE	2	2.6330	1.3165	9.284	0.0002
WR	2	0.0658	0.0329	0.232	0.7948
ER	1	0.0060	0.0060	0.042	0.8378
SGW	4	0.1888	0.0472	0.333	0.8566
SGE	2	0.1202	0.0601	0.424	0.6579
SGR	2	0.3296	0.1648	1.162	0.3135
SWE	4	2.2591	0.5648	3.983	0.0042
SWR	4	0.6156	0.1539	1.085	0.3634
SER	2	0.0725	0.0363	0.256	0.7763
GWE	2	0.6333	0.3167	2.233	0.1101
GWR	2	0.0075	0.0038	0.026	0.9741
GER	1	0.0003	0.0003	0.002	0.9647
WER	2	0.0692	0.0346	0.244	0.7854
SGWE	4	0.5715	0.1429	1.008	0.4027
SGWR	4	0.2204	0.0551	0.389	0.8179
SGER	2	0.1311	0.0655	0.462	0.6335
SWER	4	3.2110	0.8028	5.661	0.0003
GWER	2	0.3304	0.1652	1.165	0.3126
SGWER	4	0.3967	0.0992	0.699	0.5965
Subj w Groups	144	20.4191	0.1418		

Table 32 Analysis Of Variance For The 1986 Salmon Fry Stranding Study From The Middle Reach With 4,000 CFS Amplitude

Analysis of Variance — Dependent variable: LOGNUM
For the subgroup: RIVLOC = 1 A = 2

Source	df	SS (H)	MSS	F	P
Between Subjects	215	44.2102			
S (S)	2	8.6443	4.3222	30.113	0.0000
G (SUBSTR)	1	0.1101	0.1101	0.767	0.3825
W (WEEKN)	2	0.6158	0.3079	2.145	0.1199
E (E)	1	0.3077	0.3077	2.144	0.1454
R (R)	1	0.0026	0.0026	0.018	0.8931
SG	2	2.1999	1.1000	7.664	0.0007
SW	4	2.2812	0.5703	3.973	0.0043
SE	2	0.0798	0.0399	0.278	0.7596
SR	2	0.0097	0.0048	0.034	0.9671
GW	2	0.1272	0.0636	0.443	0.6456
GE	1	0.0023	0.0023	0.016	0.8936
GR	1	0.0032	0.0032	0.022	0.8811
WE	2	0.7728	0.3864	2.692	0.0706
WR	2	0.2910	0.1455	1.014	0.3629
ER	1	0.0765	0.0765	0.533	0.4664
SGW	4	0.7561	0.1890	1.317	0.2645
SGE	2	0.1762	0.0881	0.614	0.5461
SGR	2	0.1606	0.0803	0.559	0.5759
SWE	4	0.3255	0.0815	0.569	0.6881
SWR	4	0.6750	0.1688	1.176	0.3217
SER	2	0.9836	0.4918	3.426	0.0349
GWE	2	0.4999	0.2500	1.741	0.1776
GWR	2	0.3353	0.1676	1.168	0.3117
GER	1	0.0804	0.0804	0.560	0.4554
WER	2	0.6911	0.3456	2.408	0.0930
SGWE	4	0.6947	0.1737	1.210	0.3069
SGWR	4	0.5252	0.1313	0.915	0.4611
SGER	2	1.0971	0.5486	3.822	0.0240
SWER	4	0.0634	0.0158	0.110	0.9789
GWER	2	0.0778	0.0389	0.271	0.7648
SGWER	4	0.8746	0.2186	1.523	0.1970
Subj w Groups	144	20.6686	0.1435		

Table 33 Analysis Of Variance For The 1986 Salmon Fry Stranding Study From The Lower Reach With 2,000 CFS Amplitude

Analysis of Variance   Dependent variable: LOGNUM
For the subgroup: RIVLOC = 2   A = 1

Source	df	SS (H)	MSS	F	P
Between Subjects	203	72.8079			
S (S)	2	11.5994	5.7997	20.058	0.0000
G (SUBSTR)	1	2.1153	2.1153	7.316	0.0077
W (WEEKN)	2	0.6844	0.3422	1.183	0.3072
E (E)	1	0.0592	0.0592	0.205	0.6518
R (R)	1	1.7494	1.7494	6.050	0.0152
SG	2	1.2435	0.6217	2.150	0.1196
SW	4	0.2077	0.0519	0.180	0.9490
SE	2	0.2254	0.1127	0.390	0.6803
SR	2	0.4344	0.2172	0.751	0.4776
GW	2	0.7961	0.3960	1.377	0.2542
GE	1	0.1596	0.1596	0.552	0.4588
GR	1	0.8858	0.8858	3.064	0.0824
WE	2	2.8819	1.4410	4.984	0.0081
WR	2	0.2588	0.1294	0.447	0.6428
ER	1	0.0675	0.0675	0.233	0.6299
SGW	4	1.9612	0.4903	1.696	0.1536
SGE	2	0.1590	0.0795	0.275	0.7618
SGR	2	0.4024	0.2012	0.696	0.5040
SWE	4	0.8362	0.2091	0.723	0.5808
SWR	4	0.9857	0.2464	0.852	0.4983
SER	2	0.9577	0.4788	1.656	0.1934
GWE	2	0.1324	0.0662	0.229	0.7972
GWR	2	0.0556	0.0278	0.096	0.9090
GER	1	0.2521	0.2521	0.872	0.3521
WER	2	3.2209	1.6104	5.570	0.0047
SGWE	4	0.2866	0.0716	0.248	0.9112
SGWR	4	0.1015	0.0254	0.088	0.9862
SGER	2	0.2446	0.1223	0.423	0.6584
SWER	4	1.2998	0.3250	1.124	0.3455
GWER	2	0.1196	0.0598	0.207	0.8148
SGWER	4	0.2572	0.0643	0.222	0.9261
Subj w Groups	132	38.1669	0.2891		

Table 34 Analysis Of Variance For The 1986 Salmon Fry Stranding Study From The Lower Reach With 4,000 CFS Amplitude

Analysis of Variance — Dependent variable: LOGNUM
For the subgroup: RIVLOC = 2 A = 2

Source	df	SS (H)	MSS	F	P
Between Subjects	203	63.1274			
S (S)	2	7.0355	3.5177	15.519	0.0000
G (SUBSTR)	1	2.4467	2.4467	10.794	0.0013
W (WEEKN)	2	3.3292	1.6646	7.343	0.0009
E (E)	1	0.0869	0.0869	0.383	0.5368
R (R)	1	0.3349	0.3349	1.477	0.2264
SG	2	2.5749	1.2875	5.680	0.0043
SW	4	1.8863	0.4716	2.080	0.0853
SE	2	0.0753	0.0377	0.166	0.8482
SR	2	0.2031	0.1016	0.448	0.6425
GW	2	0.5294	0.2647	1.168	0.3120
GE	1	0.0321	0.0321	0.142	0.7074
GR	1	0.8964	0.8964	3.954	0.0488
WE	2	0.8043	0.4022	1.774	0.1724
WR	2	1.4057	0.7028	3.101	0.0480
ER	1	0.2497	0.2497	1.102	0.2958
SGW	4	1.9461	0.4865	2.146	0.0780
SGE	2	0.2500	0.1250	0.552	0.5805
SGR	2	0.8900	0.4450	1.963	0.1434
SWE	4	0.4492	0.1123	0.495	0.7410
SWR	4	1.1427	0.2857	1.260	0.2868
SER	2	0.0265	0.0132	0.058	0.9437
GWE	2	0.1999	0.1000	0.441	0.6469
GWR	2	0.3686	0.1843	0.813	0.4497
GER	1	0.0734	0.0734	0.324	0.5702
WER	2	1.1540	0.5770	2.545	0.0817
SGWE	4	0.5825	0.1456	0.642	0.6358
SGWR	4	0.9346	0.2337	1.031	0.3911
SGER	2	0.3604	0.1802	0.795	0.4577
SWER	4	0.7513	0.1678	0.829	0.5127
GWER	2	1.2483	0.6241	2.753	0.0669
SGWER	4	0.9380	0.2345	1.035	0.3891
Subj w Groups	132	29.9214	0.2267		

Table 35 Analysis Of Variance For The 1986 Salmon Fry Stranding Study Pooled Over Endflows And Week Numbers

Analysis of Variance — Dependent variable: LOGNUM

Source	df	SS (H)	MSS	F	P
Between Subjects	839	224.9760			
L (RIVLOC)	1	1.1782	1.1782	5.531	0.0189
A (AMP)	1	0.0017	0.0017	0.008	0.9288
S (SLOPE)	2	34.8158	17.4079	81.725	0.0000
G (SUBSTR)	1	1.9845	1.9845	9.317	0.0024
R (RRATE)	1	1.0667	1.0667	5.008	0.0255
LA	1	0.0376	0.0376	0.176	0.6746
LS	2	0.0890	0.0445	0.209	0.8127
LG	1	2.6588	2.6588	12.482	0.0005
LR	1	0.7587	0.7587	3.562	0.0595
AS	2	0.1302	0.0651	0.306	0.7386
AG	1	0.0362	0.0362	0.170	0.6806
AR	1	0.1687	0.1687	0.792	0.3738
SG	2	0.4352	0.2176	1.021	0.3580
SR	2	1.5454	0.7727	3.629	0.0268
GR	1	0.8278	0.8278	3.886	0.0490
LAS	2	0.1851	0.0925	0.434	0.6502
LAG	1	0.0966	0.0966	0.454	0.5009
LAR	1	0.1118	0.1118	0.525	0.4689
LSG	2	5.8948	2.9474	13.837	0.0000
LSR	2	0.0387	0.0194	0.091	0.9134
LGR	1	0.9849	0.9849	4.624	0.0318
ASG	2	0.0077	0.0038	0.018	0.9823
ASR	2	0.6195	0.3097	1.454	0.2326
AGR	1	0.0019	0.0019	0.009	0.9257
SGR	2	0.2907	0.1454	0.682	0.5091
LASG	2	0.3888	0.1944	0.913	0.4061
LASR	2	0.4241	0.2120	0.995	0.3744
LAGR	1	0.0042	0.0042	0.020	0.8882
LSGR	2	1.3366	0.6683	3.138	0.0436
ASGR	2	0.1431	0.0715	0.336	0.7169
LASGR	2	0.0122	0.0061	0.029	0.9719
Subj w Groups	792	168.7008	0.2130		

FIGURE 42

STACKED BAR GRAPHS SHOWING THE EFFECT OF SLOPE ON SALMON FRY GRAVEL BAR STRANDING AT DIFFERENT LEVELS OF OTHER TESTING FACTORS

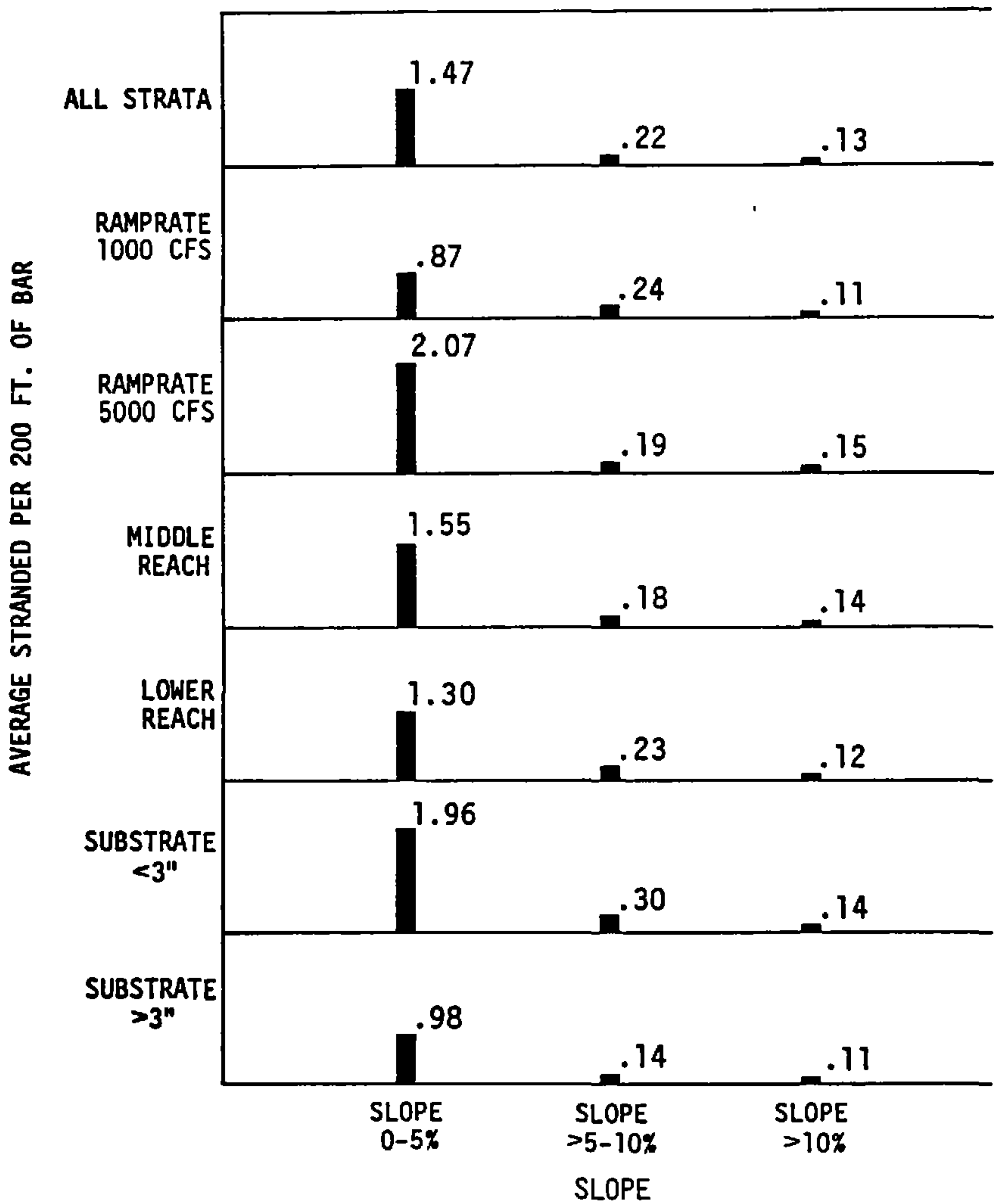


FIGURE 43

STACKED BAR GRAPHS SHOWING THE EFFECT OF DOWNRAMP AMPLITUDE ON SALMON FRY GRAVEL BAR STRANDING AT DIFFERENT LEVELS OF OTHER TESTING FACTORS

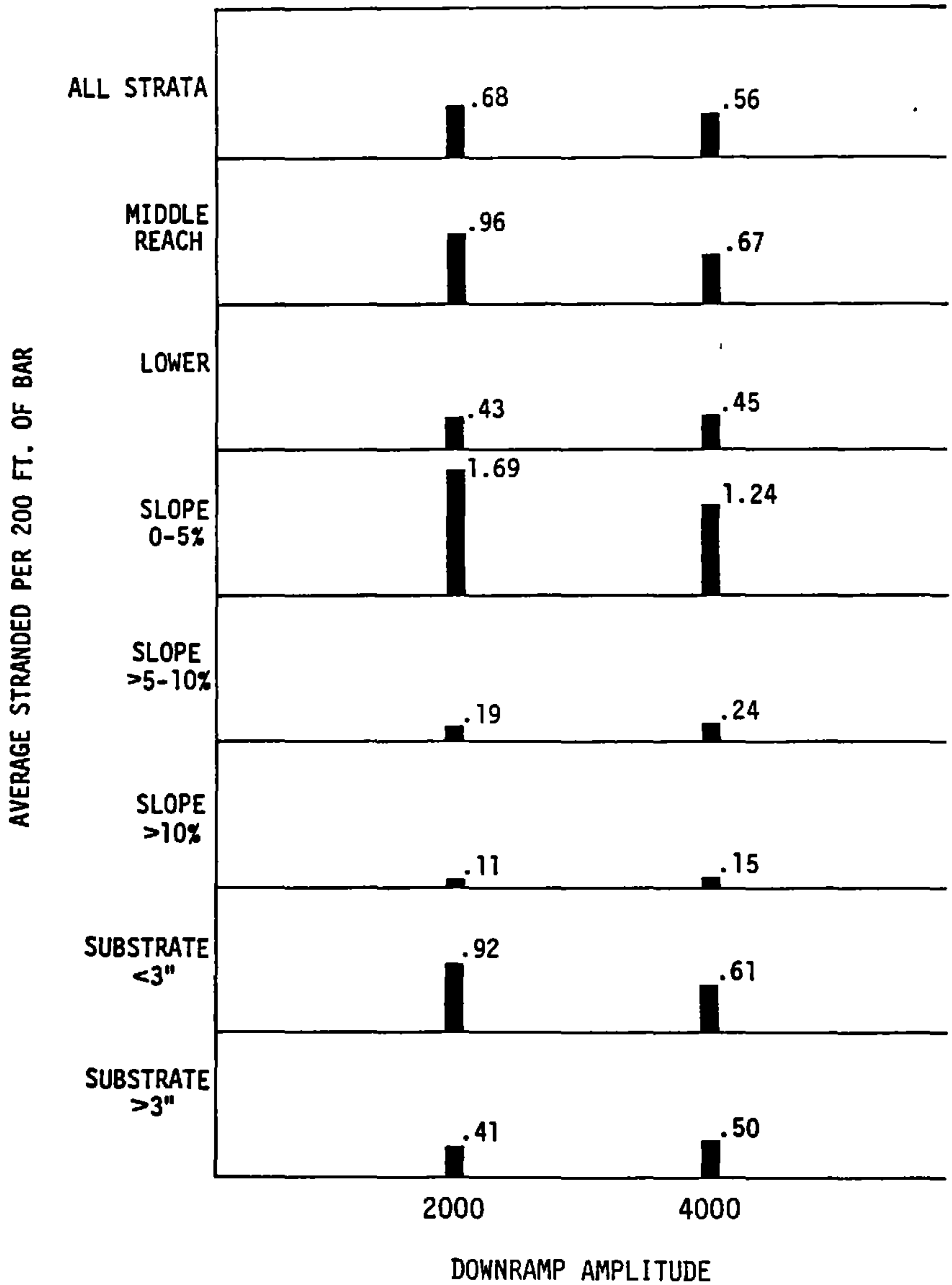


FIGURE 44

STACKED BAR GRAPHS SHOWING THE EFFECT OF RIVER LOCATION ON SALMON FRY GRAVEL BAR STRANDING AT DIFFERENT LEVELS OF OTHER TESTING FACTORS

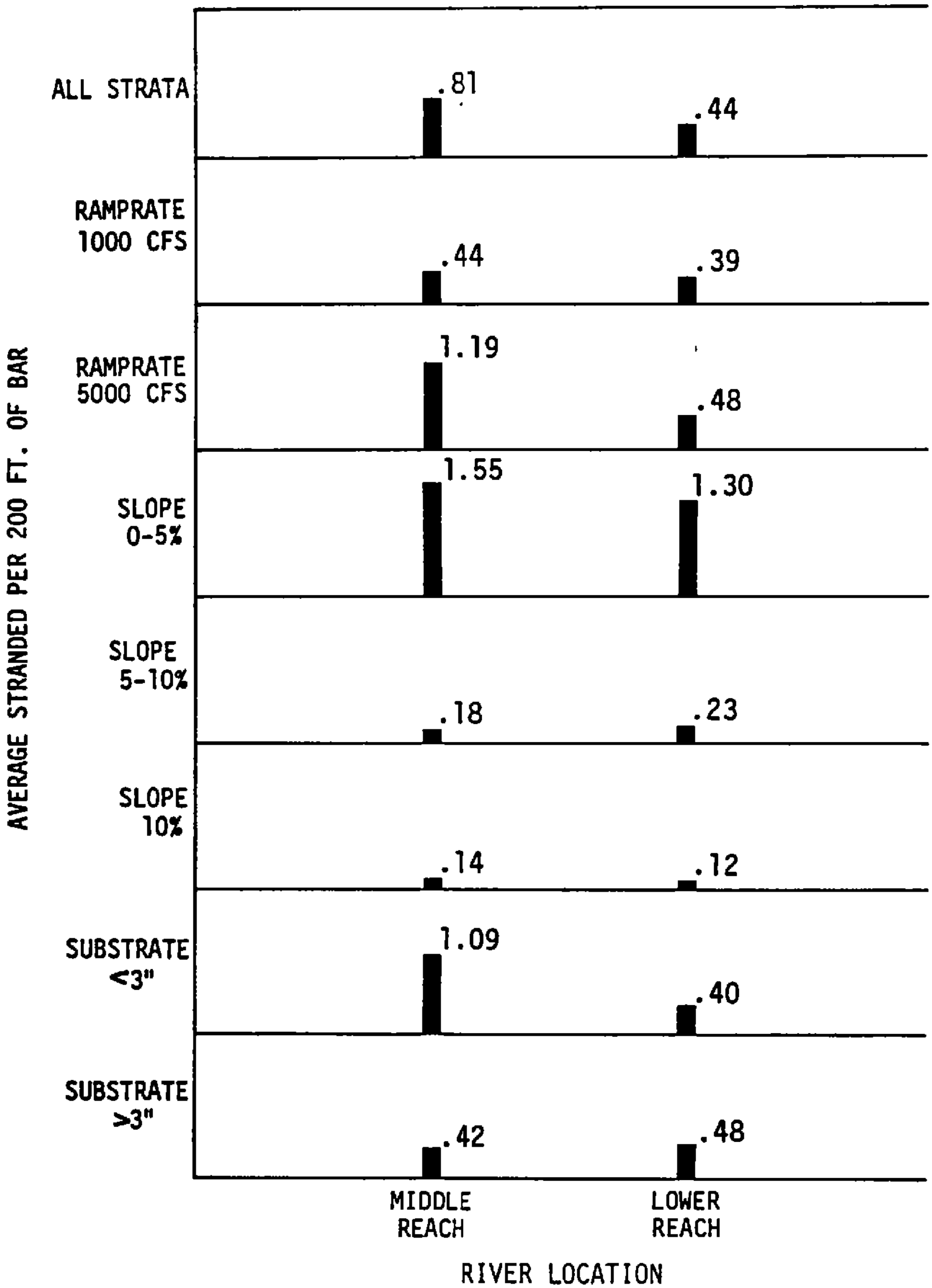


FIGURE 45

STACKED BAR GRAPHS SHOWING THE EFFECT OF RATE OF DOWNRAMPING ON SALMON FRY GRAVEL BAR STRANDING AT DIFFERENT LEVELS OF OTHER TESTING FACTORS

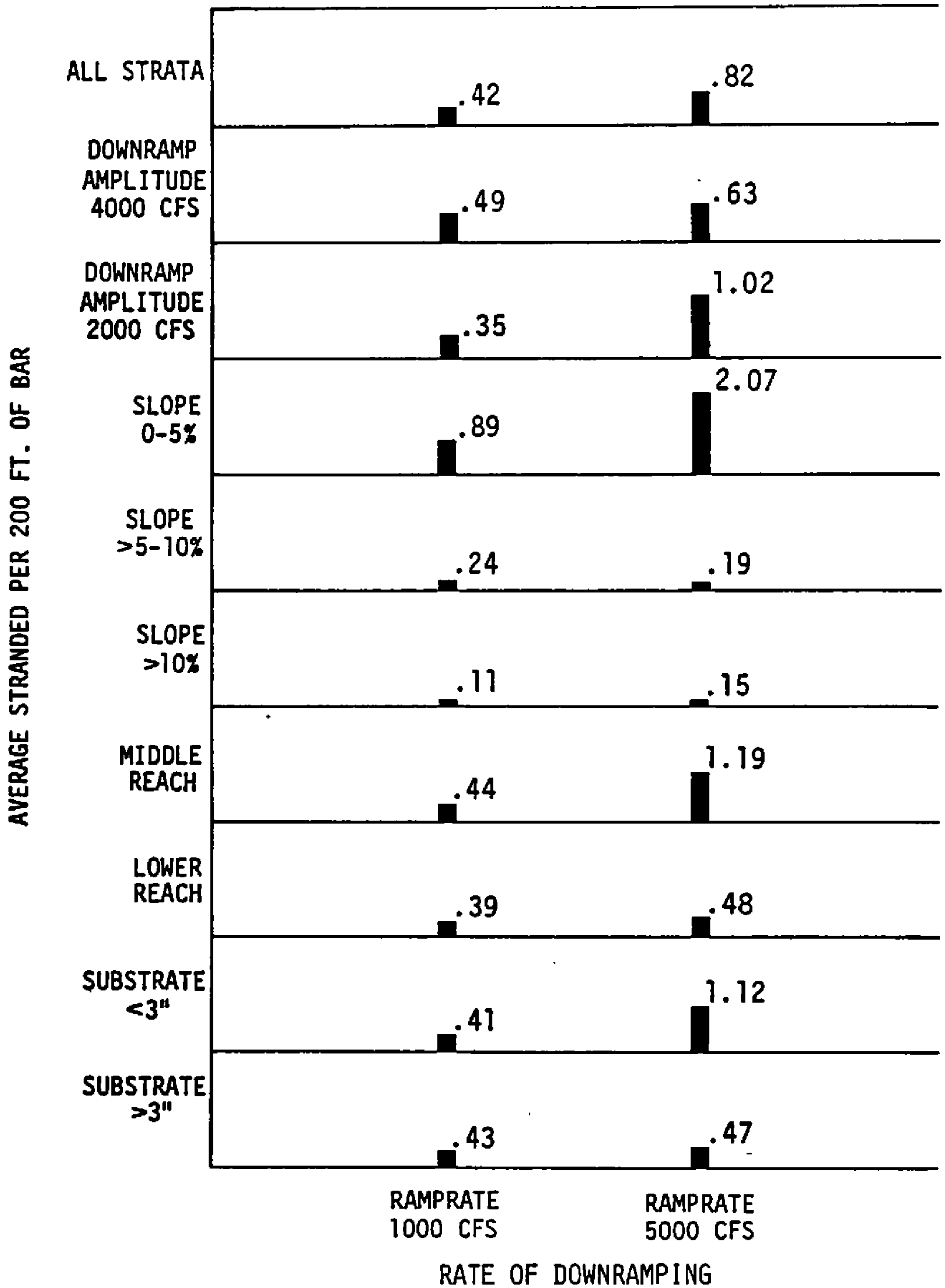
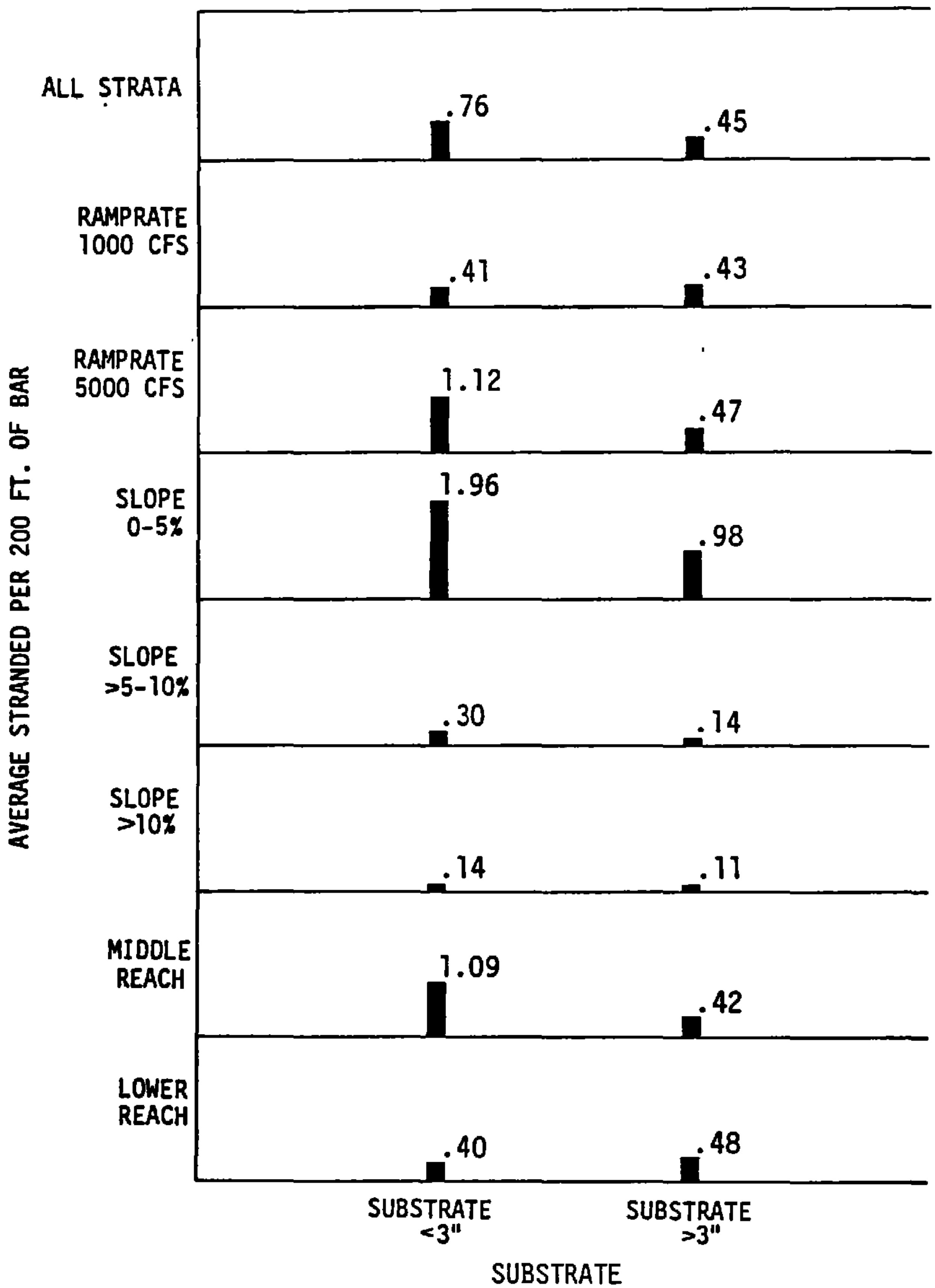


FIGURE 46

STACKED BAR GRAPHS SHOWING THE EFFECT OF SUBSTRATE ON SALMON FRY GRAVEL BAR STRANDING AT DIFFERENT LEVELS OF OTHER TESTING FACTORS



a. Slope

Slope demonstrated the most dramatic effect on fry stranding of all variables examined (Tables 31-34). Thirty-four percent of the observations were made on gravel bars with slope of less than 5%, where 81% of all stranded fry were found. The distribution of gravel bars of this type along the Skagit River is thus of great importance in assessing the overall magnitude of fry stranding. Since hydrological effects seem to become accentuated on the more gradually sloping bars (0-5%), they also afford the best opportunity to examine the relative effects of hydro-operation (downramping) on fry stranding. The dramatic difference between bars with slope less than 5% and those with slope between 5-10% suggest a great sensitivity to slope in this range (Figure 42 and Appendix Table P-2).

b. Amplitude

The ANOVA analysis showed no significant effect due to amplitude (Table 35 and Appendix Table P-3). A comparison between 2,000-cfs (AMP=1) and 4,000-cfs (AMP=2) amplitude events which occurred during the same test sequence (three test sequences were completed, each consisting of eight downramping events) failed to reject the hypothesis that there was no difference between stranding due to amplitude (Table 36). These results coupled with the fact that most stranding with 4,000-cfs amplitude events occurred in the second half of the event (see Tables 37 and 38) suggest that stranding occurs near the end of the event (Figure 43).

TABLE 36

PAIRED t-TEST FOR
FIRST VERSUS SECOND HALF OF 4,000 cfs
AMPLITUDE TESTS
SALMON FRY GRAVEL BAR STRANDING 1986

Paired Differences t-Tests

Variables	N	Means*	S.D.'s	S.D. (Diff)	t	P
2nd 2,000 cfs	420	0.195	0.443	0.501	4.905	0.001
1st 2,000 cfs		0.075	0.281			

*transformed data

TABLE 37
SIGNED RANKS TEST FOR FIRST VERSUS SECOND HALF
OF 4,000 CFS AMPLITUDE TESTS

Wilcoxon Signed-Ranks Tests

Dependent Variables(1)	N	Mean(1)	S.D. Diff.	T (P-Val)		Signed Ranks +	Signed Ranks -	Tie	Z (P-Val)
2nd 2,000 cfs		0.405			N	75	26	319	
	420		1.405	3.68	Mean				4.69
1st 2,000 cfs		0.152		(.0003)	Rank	52.287	47.288		
(.0000)									

(significant)

(1) - The statistical tests in Tables 36 and 37 show that the second half stranding was significantly greater than first half stranding. Mean stranding count for second half was 0.405 versus 0.152 for first half.

The contrast with the results reported for steelhead is noteworthy. Doubling of the amplitude more than doubled steelhead stranding. More significant effects due to amplitude for chinook might be present at higher fry densities; however, in this study even the smallest slope stratum (0-5% where stranding was highest) showed no significance (Table 38).

TABLE 38

STATISTICAL TEST OF THE AMPLITUDE
EFFECT ON SALMON FRY STRANDING IN 1986
USING ONLY OBSERVATIONS WHERE GRAVEL BAR SLOPE
WAS LESS THAN 5%

Mann-Whitney Test

Group 1 is AMP=1 (2,000 cfs)
Group 2 is AMP=2 (4,000 cfs)

Dependent Variable	Group	N	Mean	Mean Rank	Mann-Whitney "U" Statistic	Z
NUMFISH	1	144	1.694	146.135		
(Average					10,132.5	0.165
Stranded)	2	144	1.243	142.865		(Not
Significant)						

c. Endflow

The two downramp ending flow levels corresponding to approximately 3,000 and 3,500 cfs were not significantly different with respect to stranding under any test conditions (Tables 31-34). The average number of fry stranded per 200 feet of gravel bar were 0.76 and 0.48 respectively for 3,000 and 3,500 cfs endflow as measured at Marblemount (Table 39 and Appendix Table P-4).

TABLE 39

STATISTICAL TEST OF THE EFFECT OF DOWNRAMPING
ENDING FLOW ON SALMON FRY
GRAVEL BAR STRANDING IN 1986
THE DIFFERENCE BETWEEN THE TWO LEVELS
(3,000 CFS VERSUS 3,500 CFS) WAS NOT SIGNIFICANT

Mann-Whitney Test

Group 1 is ENDFLO=1 (3,000 cfs)
Group 2 is ENDFLO=2 (3,500 cfs)

Dependent Variable	Group	N	Mean	Mean Rank	Mann-Whitney "U" Statistic	Z
NUMFISH	1	420	0.757	429.050		
(Average					91,791	1.021
Stranded)	2	420	0.483	411.950		(Not Significant)

d. Location On River ("River Location")

The ANOVA (Table 35) indicates a significant difference between middle and lower river bar sites. The means plotted in Figure 44 show this effect to be most pronounced when ramping rate was 5,000 cfs/hr or when only small (less than 3 inch) substrate sites are included. As was the case with steelhead, there seems to be a tendency for hydrologic effects on stranding to be greater toward the upper reaches.

e. Ramping Rate

Ramping rate does appear to affect salmon fry stranding. Under conditions which generally favor stranding (gentle slope, middle river, small substrate and low amplitude), the higher ramping rate of 5,000 cfs/hr stranded significantly more fry than the 1,000 cfs/hr rate (Figure 45 and Table 40). As noted before, the statistical significance of tests are reduced by the preponderance of zeros (75% of all observations were zero or "no fry" observations). However, the consistently higher rate of stranding at 5,000 cfs/hr than at 1,000 cfs/hr strongly suggests a significant sensitivity to ramping rate in this range (Figure 45 and Appendix Table P-5).

TABLE 40

STATISTICAL TEST OF THE 1,000 CFS/HR (RRATE=1)
VERSUS 5,000 CFS/HR (RRATE=2) RAMPING RATES
ON GRAVEL BARS WITH A GENTLE SLOPE (0-5%)
1986 SALMON FRY STRANDING

Mann-Whitney Test
Group 1 is RRATE=1 (1,000 cfs/hr)
Group 2 is RRATE=2 (5,000 cfs/hr)

Dependent Variable	Group	N	Mean	Mean Rank	Mann-Whitney "U" Statistic	Z
NUMFISH	1	144	0.868	136.347		
(Average					11,542	1.661
Stranded)	2	144	2.069	152.653		(Significant at alpha = .05)

f. Substrate

The two levels of substrate less than 3 inches and greater than 3 inches tested significant (Table 35). As was the case with ramping rate, the effect of substrate was greatest in strata with small slope and high stranding rates (Table 41, Figure 46, and Appendix Table P-6).

TABLE 41

STATISTICAL TEST OF SMALL SUBSTRATE (SUBSTR=1)
VERSUS LARGE SUBSTRATE (SUBSTR=2)
ON GENTLE SLOPE GRAVEL BARS (0-5%)
1986 SALMON FRY STRANDING

Mann-Whitney Test
Group 1 is SUBSTR=1 (Small Substrate Less than 3")
Group 2 is SUBSTR=2 (Large Substrate Greater than 3")

Dependent Variable	Group	N	Mean	Mean Rank	Mann-Whitney "U" Statistic	Z
NUMFISH	1	144	1.958	153.934		
(Average					11,726	1.922
Stranded)	2	144	0.979	135.066		(Significant)

3. FRY STRANDING LOCATION RELATIONSHIPS

Precise stranding locations of fry may be influenced by several factors including downramping rate, amplitude fluctuation of the downramp, ending flow of the downramp, and physical features on each gravel bar. The purpose of this task was to explore the gravel bar stranding location with respect to these factors.

Twenty-nine of the 35 gravel bar study sites stranded salmon fry or steelhead juveniles during 23 days of testing (See Appendix Q). Only four of these sites had any physical features on them. Only at Rockport Bar Site 1 did three fry strand in a depression found on the gravel bar. At the other three gravel bar sites (Rockport Bar Site 2, Diobsud Creek Site 2, and Oink Bar Site 1) fry were not stranded anywhere near a gravel bar feature.

The only other relationship that developed from these plots was a visual evaluation of fish stranded on gravel bars between the 3,500 and 3,000 cfs endflows (as measured at the Marblemount gage). Prior to these tests, there was some concern that habitat dewatered below an endflow of 3,500 cfs could strand large numbers of fry. The study results show that this endflow does not represent a threshold level below which fry stranding is significantly greater (see plots). On nearly 2 of every 3 gravel bar sites, fry were stranded between the 3,500 and 3,000 cfs endflow waterlines. But the numbers of fry were generally very low, ranging from 2 to 7 fry stranded during 23 tests. The only exception to this was at Marblemount Bar Site 3 where 46 fry were stranded. A review of these plots demonstrates that fry are not stranded disproportionally on the segment of a gravel bar dewatered between flows at Marblemount of 3,000 to 3,500 cfs.

A comparison of fry stranding location to downramping rate or amplitude could not be made due to the lack of sufficient numbers of stranded fry for a particular test type.

4. SIGNIFICANCE OF GRAVEL BAR STRANDING

The intent of this study task was to develop a method for approximating the magnitude of fry stranded on gravel bars between Newhalem and Rockport Bar given certain hydrologic conditions relating to the amplitude fluctuation of a downramp event, the downramp rate, and the endflow achieved at the end of a downramp event. The results of the matrix produced can be applied to the daily dam operations to obtain a rough estimate the magnitude of fry stranded on gravel bars through the season.

The first of the two-step process involved construction of a matrix that contains two different data types: the left side of the matrix shows the average number of salmon fry stranded per 200 feet of gravel bar given a specific combination of reach location, amplitude fluctuation, ramping rate, downramp endflow, bar slope, and substrate (Figure 47). These data were derived from the results of the gravel bar stranding tests and within the limits of the study. Each value in this part of the matrix resulted from the summation of the total fry stranded divided by the total number of replicates having a specific combination of the six variables listed above. (See example Figure 35.) The values representing the upper river reach are identical to those calculated for the middle reach. The right side of the matrix is a breakdown and distribution of the gravel bar types found in all three reaches of the study area. These gravel bars are categorized by reach location, bar slope, and dominant substrate type. For a more detailed discussion see Section V of this report.

The average number of fry stranded/200 feet of gravel bar ranged from 0.0 to 8.9 depending on the type of gravel bar and downramp type. The highest value in the matrix was represented by the following combination of factors: a downramp amplitude of 2,000 cfs, a 5,000 cfs/hour downramping rate and a 3,000 cfs downramp endflow; combined with a gravel bar slope of less than 5% and dominant substrate less than 3 inches.

The second step in the process was the development of a matrix which provides an estimate for the total number of salmon fry stranded on gravel bars within the 26-mile study area for eight different downramping scenarios (Figure 48). Each cell in this matrix is the product of the average number of fry/200 feet of gravel bar for that cell type and the number of 200-foot-long segments of gravel bar within each river reach. (See example in Figure 35.) Each cell of the matrix contains three different values representing the stranded salmon fry for the upper, middle, and lower river reaches. Each of the eight columns in the matrix represent a different type of downramp scenario. The cumulative sum of each column is the relative number of salmon fry stranded for the entire study area from Newhalem to Rockport for the eight respective downramp scenarios. The lowest fry strand total was produced by a 2,000 cfs downramp amplitude fluctuation combined with a 3,500 cfs endflow and 1,000 cfs downramp rate. The highest fry strand total was produced by a 2,000 cfs amplitude fluctuation combined with a 3,000 cfs endflow and a 5,000 cfs/hour downramp rate.

To determine the magnitude of salmon fry gravel bar stranding on the Skagit River from Newhalem to Rockport these daily estimates must be applied to the period of peak vulnerability, which conservatively seems to be 120 days in length (February 1 to May 30). A possible "high side" estimation assumes maximum daily stranding of 162.6 fry/day, multiplied by the 120-day vulnerability period for a total of 19,512 salmon fry stranded per season. Every other year pink salmon fry would not contribute to the total stranded which would represent a 30% (see Table 26) reduction translating to 13,658 fry stranded per season. The total number of stranded fry per year would vary depending on how the hydroelectric project is actually operated, adult escapement, egg-to-fry survival, and the type and amount of gravel bars which all change from year to year. The magnitude estimate developed above does not account for several sources of error such as observer error and predation on fry

FIGURE 47

MATRIX SHOWING THE AVERAGE NUMBER OF STRANDED SALMON FRY FOR 48 DIFFERENT COMBINATIONS OF GRAVEL BAR SLOPES, AND SUBSTRATE BY DOWNRAMP AMPLITUDE, AND RAMPRATE IN ADDITION TO GRAVEL BAR REACH LOCATIONS AND LENGTHS.
SPRING 1986

		DOWNRAMP AMPLITUDE 2000 cfs				DOWNRAMP AMPLITUDE 4000 cfs				GRAVEL BAR LOCATION AND LENGTH (Lineal Feet)		
		DOWNRAMP ENDFLOW 3500 cfs		DOWNRAMP ENDFLOW 3000 cfs		DOWNRAMP ENDFLOW 3500 cfs		DOWNRAMP ENDFLOW 3000 cfs				
GRAVEL BAR SLOPE (%)	PRIMARY SUBSTRATE SIZE (Inches)	RAMPRATE (cfs/hour) 1000	RAMPRATE (cfs/hour) 5000	RAMPRATE (cfs/hour) 1000	RAMPRATE (cfs/hour) 5000	RAMPRATE (cfs/hour) 1000	RAMPRATE (cfs/hour) 5000	RAMPRATE (cfs/hour) 1000	RAMPRATE (cfs/hour) 5000	UPPER REACH	MIDDLE REACH	LOWER REACH
0-5%	<3"	U=0.917 M=0.917 L=0.83	U=1.75 M=1.75 L=1.5	U=0.83 M=0.83 L=0.5	U=8.917 M=8.917 L=2.0	U=0.633 M=0.833 L=0.5	U=2.08 M=2.08 L=0.5	U=1.33 M=1.33 L=0.5	U=3.167 M=3.167 L=0.834	700	1,200	5,800
	>3"	U=0.677 M=0.677 L=0.677	U=0.917 M=0.917 L=2.167	U=0.5 M=0.5 L=0.5	U=0.667 M=0.667 L=2.167	U=0.916 M=0.916 L=2.666	U=0.25 M=0.25 L=1.167	U=0.583 M=0.583 L=1.33	U=0.500 M=0.500 L=2.83	1,200	600	600
>5%-10%	<3"	U=0.0 M=0.0 L=0.25	U=0.500 M=0.500 L=0.25	U=0.167 M=0.167 L=0.167	U=0.0 M=0.0 L=0.333	U=0.500 M=0.500 L=0.583	U=0.0 M=0.0 L=0.167	U=0.0 M=0.0 L=0.0	U=0.334 M=0.334 L=0.583	1,200	1,000	2,400
	>3"	U=0.0 M=0.0 L=0.133	U=0.333 M=0.333 L=0.0	U=0.167 M=0.167 L=0.267	U=0.0 M=0.0 L=0.0	U=0.0 M=0.0 L=0.0	U=0.334 M=0.334 L=0.067	U=0.334 M=0.334 L=0.400	U=0.167 M=0.167 L=0.20	3,110	1,400	2,000
>10%	<3"	U=0.0 M=0.0 L=0.222	U=0.167 M=0.167 L=0.0	U=0.0 M=0.0 L=0.111	U=0.333 M=0.333 L=0.111	U=0.25 M=0.25 L=0.0	U=0.25 M=0.25 L=0.111	U=0.0 M=0.0 L=0.333	U=0.25 M=0.25 L=0.0	2,000	800	2,000
	>3"	U=0.0 M=0.0 L=0.167	U=0.0 M=0.0 L=0.167	U=0.0 M=0.0 L=0.167	U=0.0 M=0.0 L=0.0	U=0.0 M=0.0 L=0.0	U=0.334 M=0.334 L=0.0	U=0.333 M=0.333 L=0.167	U=0.333 M=0.333 L=0.0	1,850	400	800

Upper Reach — U=0.0
Middle Reach — M=0.0
Lower Reach — L=0.0

AVERAGE NUMBER OF FRY STRANDED/200 FT OF GRAVEL BAR FOR DIFFERENT COMBINATIONS OF BAR SLOPE, SUBSTRATE, RAMPRATE, AND AMPLITUDE FLUCTUATION OF A DOWNRAMP EVENT (1).

(1). See Figure 34 for typical method of calculation for each Stranding Prediction scenario.

FIGURE 48

MATRIX PREDICTING TOTAL SALMON FRY STRANDED WITHIN THE THREE REACH STUDY AREA FOR EIGHT DIFFERENT DOWNRAMP SCENARIOS. SPRING 1986

		DOWNRAMP AMPLITUDE 2000 cfs				DOWNRAMP AMPLITUDE 4000 cfs			
		DOWNRAMP ENDFLOW 3500 cfs		DOWNRAMP ENDFLOW 3000 cfs		DOWNRAMP ENDFLOW 3500 cfs		DOWNRAMP ENDFLOW 3000 cfs	
GRAVEL BAR SLOPE (%)	PRIMARY SUBSTRATE SIZE (inches)	RAMPRATE (cfs/hour)		RAMPRATE (cfs/hour)		RAMPRATE (cfs/hour)		RAMPRATE (cfs/hour)	
		1000	5000	1000	5000	1000	5000	1000	5000
0-5%	<3"	U=3.2 M=5.5 L=24.1	U=6.1 M=10.5 L=43.5	U=2.9 M=5.0 L=14.5	U=31.2 M=53.5 L=58.0	U=2.9 M=5.0 L=14.5	U=7.3 M=12.5 L=14.5	U=4.7 M=8.0 L=14.5	U=11.1 M=25.3 L=24.2
	>3"	U=4.0 M=2.0 L=2.0	U=5.5 M=2.8 L=6.5	U=3.0 M=1.5 L=1.5	U=4.0 M=2.0 L=6.5	U=5.5 M=2.8 L=8.0	U=1.5 M=0.8 L=3.5	U=3.5 M=1.8 L=4.0	U=3.0 M=1.5 L=8.5
>5%-10%	<3"	U=0.0 M=1.25 L=0.0	U=3.0 M=1.25 L=6.0	U=1.0 M=0.8 L=2.0	U=0.0 M=1.7 L=0.0	U=3.0 M=2.9 L=6.0	U=0.0 M=0.8 L=0.0	U=0.0 M=0.0 L=0.0	U=2.0 M=2.9 L=4.0
	>3"	U=0.0 M=0.0 L=2.1	U=5.2 M=2.3 L=0.0	U=2.8 M=1.2 L=4.2	U=0.0 M=0.0 L=0.0	U=0.0 M=0.0 L=0.0	U=5.2 M=2.3 L=1.0	U=5.2 M=2.3 L=6.2	U=2.6 M=1.2 L=3.1
>10%	<3"	U=0.0 M=0.0 L=2.2	U=1.67 M=0.7 L=0.0	U=0.0 M=0.0 L=1.1	U=3.3 M=1.3 L=1.1	U=2.5 M=1.0 L=0.0	U=2.5 M=1.0 L=1.1	U=0.0 M=0.0 L=3.3	U=2.5 M=1.0 L=0.0
	>3"	U=0.0 M=0.0 L=0.7	U=0.0 M=0.0 L=0.7	U=0.0 M=0.0 L=0.7	U=0.0 M=0.0 L=0.0	U=0.0 M=0.0 L=0.0	U=0.0 M=0.0 L=1.4	U=3.1 M=0.7 L=0.7	U=3.1 M=0.7 L=0.0
	TOTALS	47.1	95.7	59.0	162.8	54.1	55.4	113.4	96.7

Upper Reach — U=0.0
Middle Reach — M=0.0
Lower Reach — L=0.7

} TOTAL FRY STRANDED DURING DOWNRAMP EVENT IN EACH RIVER REACH (1).

55.4 } EQUALS PREDICTED NUMBER OF STRANDED FRY FOR ALL GRAVEL BARS IN THE STUDY AREA (COLUMN TOTAL) BY TEST TYPE

(1). See Figure 34 for typical method of calculation for each Stranding Prediction scenario.

stranded on gravel bars. As such, the estimate is not intended to represent the absolute number of fry stranded but rather a relative index of the magnitude.

5. SCAVENGING OF STRANDED FRY

Juvenile salmon and steelhead stranded on gravel bars are frequently counted to get an idea of how many fry are killed by a fluctuating flow associated with hydropower generation. One constructive criticism of this method is that a large number of stranded (dead) fry could be picked up and eaten by birds or mammals before a human observer can get an accurate count at daylight. A small experiment was done to evaluate whether or not stranded fry were eaten before they could be counted.

The experiment was completed in two days and was not intended to be scrutinized with statistics or published in a scientific journal. Rather, the experiment was intended to examine something we were curious about, and make a first approximation as to the extent of the problem.

All the dead fry placed on the Marblemount gravel bar disappeared within 3 hours of being placed on the bar at 3:00 a.m. (Table 42). Dead fry placed on the other five gravel bars remained untouched (Table 42). Scavenging of dead fry was not observed directly, so it was unknown if a bird, mammal, or insects consumed the dead fry.

This experiment showed that dead salmon and steelhead fry rapidly disappeared from Marblemount Bar, and that bird or mammal scavenging was not observed at the other gravel bars tested. Crows and robins are the most likely scavengers since these omnivores are commonly seen on the gravel bars around daybreak.

Marblemount Bar was the location of the greatest number of stranded fish during the spring 1986 gravel bar stranding study, and it appeared that local scavengers had learned to feed on the fry killed each night by the fluctuating flows. Scavenging occurred during the first hour of daylight, or before, which meant that scavenging at Marblemount Bar preceded human observations of stranded fry.

This experiment suggests that scavenging of stranded fry was not a factor with the exception of Marblemount Bar where substantial numbers of fry were scavenged. Experiments similar to the one described should be done concurrent with any study of stranding on gravel bars or potholes, so as to define quantitatively what impact the early morning scavenging may have on the actual number of stranded fry. The experiment suggests some error results from scavenging of stranded fry on specific gravel bars.

TABLE 42

NUMBER OF DEAD SALMON FRY PLACED ON GRAVEL BARS ALONG THE SKAGIT RIVER, AND THE NUMBER OF FRY REMAINING DURING SUBSEQUENT CHECKS

	April 10, 1986			April 11, 1986			
Gravel Bar Name	Number of Fry Placed on Bar (Time)	Number of Fry Remaining on Bar (Time)		Number of Fry Placed on Bar (Time)	Number of Fry Remaining on Bar (Time)		% of Fry Lost to Scavengers
Oink	10 (0230)	10 (0530)	10 (0800)	None	None		0
Diobsud	None	None	None	10 (0230)	10 (0530)	10 (0730)	0
Marblemount	10 (0300)	0 (0600)	0 (0800)	15 (0300)	0 (0530)		100
Hooper's Slough ..	9 (0330)	9 (0630)	9 (0830)	None	None		0
Inaccessible	None	None	None	10 (0330)	10 (0600)		0
Rockport	11 (0330)	11 (0630)	11 (0830)	15 (0400)	15 (0700)		0

6. FRY RECRUITMENT IN POTHOLES

During this study, pothole recruitment of fry consisted mostly of chinook salmon (Table 43). Tests involving low beginning flows (5,000, 5,500 cfs) at Marblemount showed a significant increase (P less than .05) in mean numbers of fry recruited as N DAYS (the number of downramps prior to the test day with low beginning flows) increased (Table 44 and Figure 49). The initial recruitment level of 5.83 fry/pothole occurred during the first 24-hour period (N-DAY=0), in which test potholes were connected to the main river once as a result of the daily upramping event. During the next 24-hour period (N-DAY=1), recruitment increased to 12.79 fry/pothole. After three days of low beginning flows (N-DAY=2), pothole recruitment again rose to a level of 18.57 fry/pothole.

Tests conducted using high beginning flows (7,000, 7,500 cfs) showed no significant trends in recruitment (P greater than .05) (Table 44, Figure 49). As N DAY (the number of downramps prior to the test day with high beginning flows) increased, fry recruitment actually decreased. During this study, it was apparent that potholes having silt and sand bottom substrate recruited fewer fry then those having gravel and/or cobble substrate (Figure 50).

Results from the pothole residency study by Troutt and Pauley (1986) indicated fry may choose pothole areas as short-term rearing habitat. If we assume pothole residency to be a natural part in the life history of the fry, it follows that the fish will seek out these areas as rearing sites. Results from this study may reflect the propensity of fry to find areas of reduced velocity for rearing purposes.

TABLE 43

SPECIES COMPOSITION OF FRY FOUND
IN POTHOLES BETWEEN MARCH 13 AND APRIL 12
ON THE SKAGIT RIVER IN 1986

Fry Species	Number Sampled	Percent of Total Fry
Chinook	3,006	97.8
Steelhead	37	1.2
Pink	21	0.7
Coho	10	0.3

FIGURE 49 AVERAGE FRY RECRUITMENT IN POTHOLES VS. BEGINNING FLOW HISTORY AT TWO LEVELS OF BEGINNING FLOW

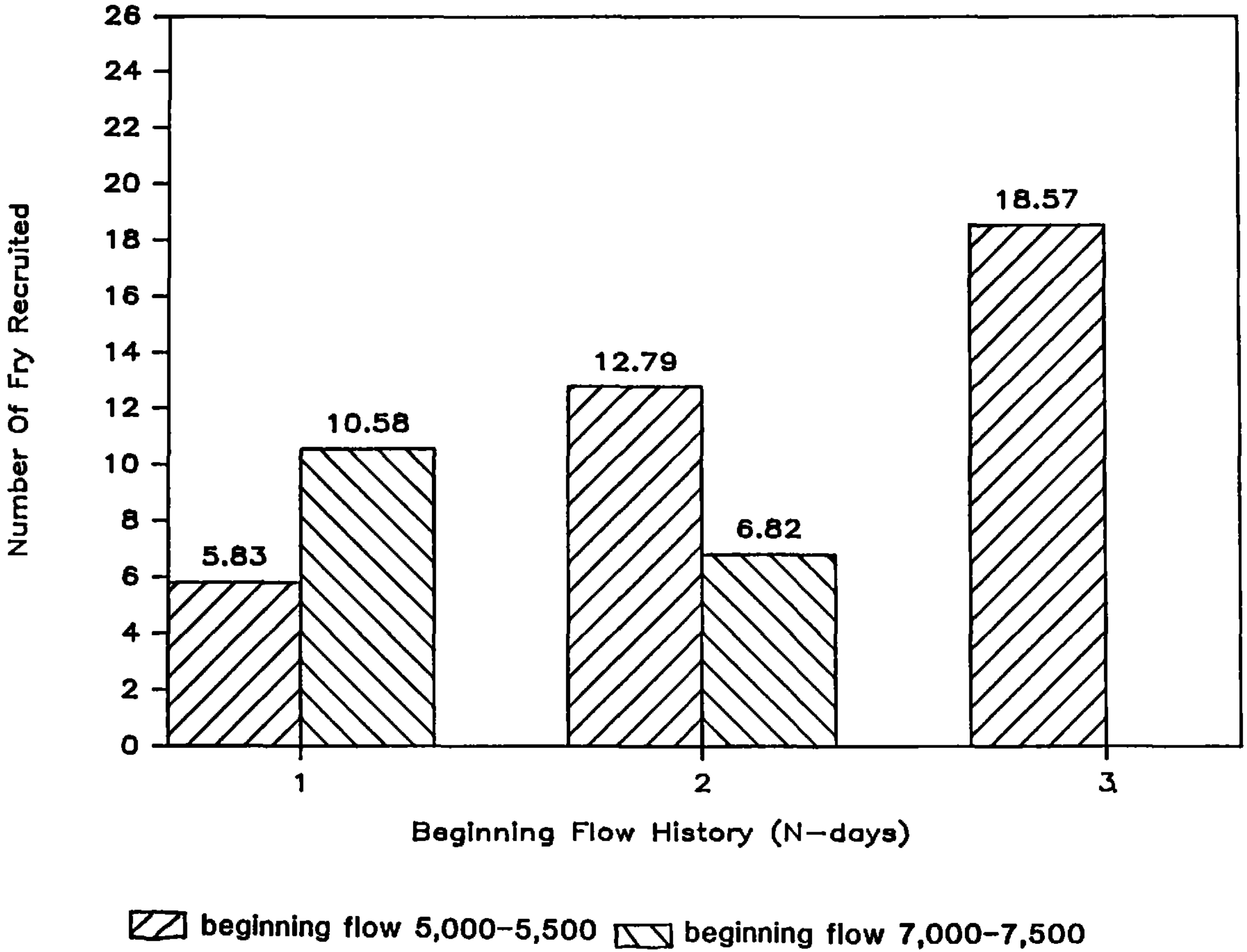


FIGURE 50 AVERAGE FRY RECRUIMENT IN POTHOLES WITH SAND AND SILT VS. GRAVEL AND COBBLE SUBSRATE

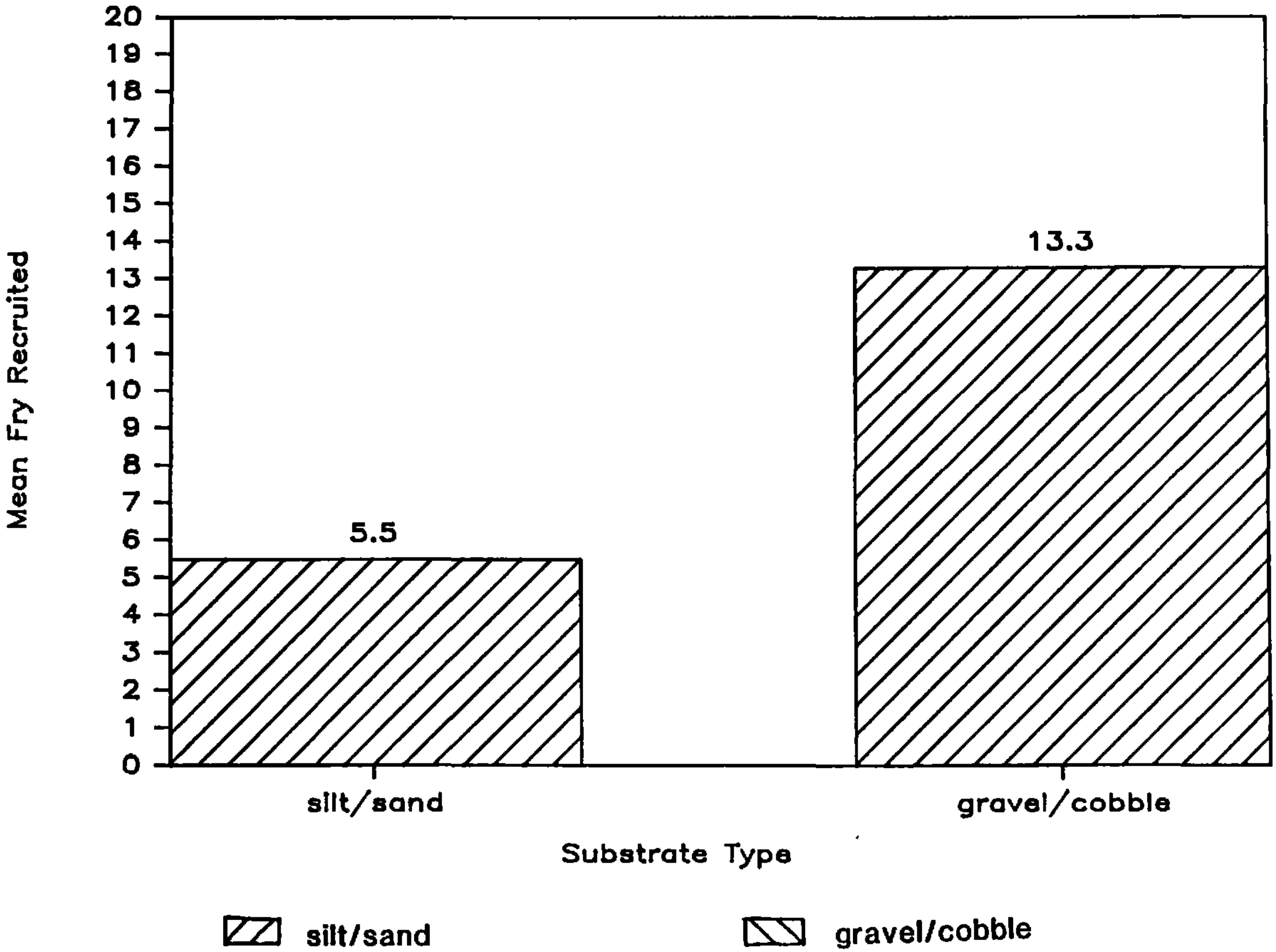


TABLE 44

RESULTS OF AVERAGE FRY RECRUITMENT
VERSUS TWO BEGINNING FLOW HISTORY LEVELS

Beginning Flow Classification(1)	N-Days(2)	Number of Observations	Average Pothole Recruitment
1	1	27	5.83
1	2	21	12.79
1	3	11	18.57
2	1	31	10.58
2	2	26	6.83
2	2	0	No Data

1 - Beginning Flow Classification at Marblemount
1 = Beginning Flow 5,000 - 5,500 cfs
2 = Beginning Flow 7,000 - 7,500 cfs

2 - N-Days is the number of downramps prior to test date having beginning flow of 5,000-5,500 cfs.

The results of this study demonstrate that a high beginning flow "erases" the recruitment which had taken place prior to such an event. Presumably a pothole is less likely to be occupied repeatedly when deeply submerged. It appears a high flow test flushes all the fry from a pothole and any recruitment after such a test probably results from fry randomly entering pothole areas as the flow level drops during the downramp. The absence of any significant trends in recruitment with high beginning flow supports this speculation. That is, trapping may be independent of low beginning flow history prior to a high beginning flow test. It does appear, however, that the number of fry trapped in potholes that repeatedly connect and disconnect with main-channel flow is dependent on the number of successive beginning flow tests that take place in between 5,000-5,500 cfs. This study shows that fry trapped numbers continue to increase until the string of low beginning flows is interrupted by a high beginning flow which starts the recruitment process over again. Furthermore, the apparent relationship between beginning flow and recruitment (or fry trapped) was also found to agree with a separate study concerning pothole trapping conducted during the spring of 1985. (See Figure 13.)

A variety of substrate and cover characteristics was observed among potholes found along the Skagit River between Rockport and Bacon Creek. Sand and silt bottom potholes without cover consistently recruited fewer fry than other potholes (Figure 50). Troutt and Pauley (1986) found that chinook fry reside longer in potholes with some degree of cover over potholes without cover. (Note Figure 50 compares recruitment to substrate but a comparison of cover is identical.) Since substrate size is partially a function of water velocity, recruitment may be dependent on both hydraulic and behavioral components. The hydraulic component regulates the likelihood of a fry moving through a pothole area during a high water event; the behavioral component affects the propensity of fry to remain in the pothole area during a downramping event.

Pothole residency appears to be a natural part in the life history of chinook fry on the Skagit River. The immediate recruitment observed during this study appears to reflect the tendency for fry to utilize preferred habitat. However, high beginning flows apparently inundate potholes and perhaps create current velocities unsuitable for fry. Accordingly, suitability seems to relate to other physical characteristics of the pothole site such as cover type and streambed gradient. Moreover, as discharge fluctuations at Gorge Powerhouse causes potholes to connect and disconnect, this study shows that fry choose to and sometimes remain in potholes for extended time periods and, as long as minimum flows do not dewater potholes, the threat of pothole stranding mortality is minimal. Further detail regarding this study can be found in Appendix R.

SECTION VII

REANALYSIS OF HISTORICAL GRAVEL BAR STRANDING DATA

1. PURPOSE

A number of gravel bar stranding studies have been conducted on the Skagit River between 1969 and 1984 by several researchers (Thompson, 1970; Phinney, 1973; Graybill et al., 1979; Stober et al., 1982; Crumley, 1984). Except for the last two years of this period, downramping rate was the primary variable examined to explain gravel bar stranding of salmon and steelhead fry. Factors such as gravel bar slope and substrate type, flow history, amplitude fluctuation of flow, and daylight vs. darkness downramping were usually not examined. One objective of this study task was to develop a database with all the past gravel bar stranding data and adding to it as much available data as possible pertaining to other variables that were not included in the original investigations. Once the computerized database was constructed, a reanalysis was completed to identify any new correlations with new or old variables. The results of the reanalysis were used, where possible, to support the design of the 1985-86 study. This was perhaps the most important purpose for the reanalysis, as the data collected from these studies were never intended to be analyzed together and, with the exception of one day versus night study, do not lend themselves to a comprehensive analysis. In other words, an experimental design could not be built around the existing data. Generally, past studies were seriously lacking in statistical design. With the exception of the day versus night study mentioned previously, these studies did not meet the minimum statistical requirements with respect to replication and statistical control.

2. APPROACH AND METHODOLOGY

The basic approach to this investigation required a complete review of all previous technical reports from 1969, the first gravel bar stranding study, to the 1983 gravel bar stranding study. The gravel bar name and location, date, and the number of chinook stranded/200 feet of gravel bar were compiled along with daily testing parameters such as downramping rate. Most of the historical stranding data were not expressed in terms of fry per 200 feet of gravel bar. This unit of comparison was derived from each study's data by conversion to establish consistency. This database was then expanded by reconstructing additional testing variables such as downramp endflow (the river flow at the end of a downramp), beginning flow (the river flow at the beginning of a downramp), downramp amplitude (cfs difference between the beginning and end flows), hours-day (when the downramp was completed in relation to sunrise), and flow history (number of hours the flow was held constant prior to a downramp). Once the reconstructed database was completed it was then subjected to qualitative and quantitative analysis. Perhaps the most significant analysis to be completed was to determine if the database could be used for statistical analysis. Because the data were never intended to be analyzed together several factors had to be explored to determine the validity of the subsequent statistical tests.

Special emphasis was placed on a statistical re-analysis of an experiment conducted each March-April of 1981-83 by the Washington State Department of Fisheries. The experiment was designed to test the effect of daylight versus darkness downramping. Our reevaluation of the experiment involved verification of the hydraulic parameters (did the downramp requested for each test actually occur) used and completion of a statistical test to verify the earlier results.

3. RESULTS

A total of 126 gravel bar observations were completed by earlier researchers between 1969-83 on the Skagit River. Table 45 contains a complete listing of all the historical gravel bar stranding data and is supplemented by reconstructed data. The table is sorted first by gravel bar site and second by the average number of stranded chinook per 200 feet of gravel bar. A legend is provided for this table that defines each "data type". Sixty-eight percent of these observations were made at Rockport and Marblemount gravel bars. The remaining 32% of the observations were made at six other gravel bar sites, all within the study area.

A distribution using the number of observations versus chinook stranded per 200 feet of gravel bar showed that 67% of the gravel bar tests had stranded 0-3 fry/200 feet of gravel bar (Figure 51). Ten percent (10%) of the tests stranded more than 25 fry/200 feet of gravel bar. It appears that there are two levels of stranding that may perhaps be influenced by some combination of hydrologic and biological conditions. The "low level" stranding zone in Figure 51, which is defined as those observations where less than 15 fry/200 feet of gravel bar were stranded, may represent a normal response to downramping. The "high level" stranding zone, which is where greater than 15 fry/200 feet of gravel bar were stranded, represents a combination of factors that causes a change in the normal response of fry to downramping.

Within the low stranding zone of Figure 51 the average stranded on all bars was 2.5 fry/bar, while the average stranded at Rockport and Marblemount Bars were 3.84 and 2.26 fry/bar respectively. Within the high stranding zone of Figure 51 the average stranded on all bars was 153.6 fry and on Rockport and Marblemount 78.1 and 207.2 respectively.

The statistical portion of the analysis started by building a study design matrix from the 83 observations made at either Rockport or Marblemount. This was needed to determine if the study design was balanced with respect to each testing parameter and each level of each parameter. For valid results from the statistical tests the resulting distribution should be balanced over the testing parameters with adequate replicates in each cell of the matrix.

Three levels of endflow (less than 3,000, 3,000-3,800, and greater than 3,800), two levels of downramping rate (less than 1,000 and greater than 1,000 cfs), two levels of downramp amplitude fluctuation (less than 3,300 and greater than 3,300 cfs), and three levels of hours-day (light vs. darkness downramping) were used in the matrix. The hours-day variable had three different levels, the first level was tests with downramps that happened at least one hour prior to calculated sunrise times, the second level was tests with downramps that

Table 45 LIST OF ALL HISTORICAL GRAVEL BAR STRANDING DATA COLLECTED ON THE SKAGIT RIVER BETWEEN 1969 - 1983

GRAVEL BAR NAME	NUMBER OF STRANDED CHINOOK FRY	DATE OF OBSERVATION (YR/MO/DAY/1)	MONTH AND DAY	ENDING FLOW RATE (CFS)	AMPLITUDE OF DOWNRAMP (CFS)	RAMPRATE (CFS/HR)	HOURS OF DAYLIGHT (HRS)	FLOW HISTORY (HRS)	GAGE
BACON CR	1.80000	7303171	317	2260	4140.00	1140.00	-2.00000	0.00000	N
BACON CR	1.00000	7303181	318	1040	3970.00	1510.00	0.00000	12.0000	N
COUNTY LINE	57.9000	7603231	323	3370	3450.00	1650.00	7.00000	27.0000	N
COUNTY LINE	20.8000	7703011	301	2730	2660.00	1010.00	7.50000	1.00000	M
COUNTY LINE	10.8000	7303171	317	2260	4140.00	1140.00	-4.00000	0.00000	N
COUNTY LINE	10.4000	7303181	318	1040	3970.00	1510.00	-2.00000	12.0000	N
COUNTY LINE	10.0000	7703301	330	2370	4240.00	1815.00	-2.00000	13.0000	N
COUNTY LINE	6.30000	7703101	310	2730	2660.00	1270.00	-6.50000	4.00000	N
COUNTY LINE	1.40000	8203101	310	2370	2110.00	435.000	-3.50000	5.00000	N
COUNTY LINE	1.10000	8203301	330	2370	2280.00	1140.00	-4.00000	16.0000	N
COUNTY LINE	0.80000	8203311	331	2370	2830.00	705.000	-5.00000	12.0000	N
COUNTY LINE	0.30000	8203171	317	2370	2640.00	835.000	-4.00000	15.0000	M
COUNTY LINE	0.30000	8203121	312	2370	2280.00	665.000	-4.50000	13.0000	N
COUNTY LINE	0.00000	7703181	318	3520	3090.00	800.000	6.00000	2.00000	M
COUNTY LINE	0.00000	8204011	401	2370	1450.00	545.000	-1.75000	1.00000	N
COUNTY LINE	0.00000	7702031	203	3520	3300.00	1395.00	9.00000	5.00000	N
COUNTY LINE	0.00000	8203111	311	2370	2280.00	580.000	-5.50000	13.0000	N
COUNTY LINE	0.00000	7604291	429	2490	2160.00	590.000	-4.50000	15.0000	M
COUNTY LINE	0.00000	8203191	319	2370	2280.00	1140.00	-4.00000	2.00000	N
COUNTY LINE	0.00000	8204021	402	2370	2280.00	1195.00	-5.75000	14.0000	N
COUNTY LINE	0.00000	8203181	318	2370	2280.00	815.000	-4.00000	1.00000	M
HOOPER SL	52.0000	7003131	313	1600	5250.00	1845.00	-3.00000	8.00000	AM
MARBLE MT	827.000	7003131	313	1600	5250.00	1845.00	-4.00000	8.00000	AM
MARBLE MT	333.300	6903141	314	1730	3620.00	1050.00	-2.00000	14.0000	AM
MARBLE MT	192.000	7003071	307	2140	4960.00	2015.00	-2.00000	48.0000	AM
MARBLE MT	179.800	7303181	318	1040	3970.00	1510.00	0.00000	12.0000	N
MARBLE MT	40.5000	7603231	323	3960	3390.00	1600.00	8.50000	27.0000	AM
MARBLE MT	33.3000	7702081	208	2920	4080.00	1570.00	-4.00000	1.00000	M
MARBLE MT	25.9000	6903291	329	3610	3040.00	1395.00	-1.00000	9.00000	M
MARBLE MT	25.5000	7303171	317	2260	4140.00	1140.00	-2.00000	0.00000	N
MARBLE MT	9.20000	7603171	317	3590	1160.00	670.000	-1.50000	18.0000	AM

PARAMETER DEFINITIONS:

STRANDED CHINOOK - NUMBER OF CHINOOK FRY STRANDED ON 200 FEET OF GRAVEL BAR.
DATE OF OBSERVATION - DATE GRAVEL BAR WAS SAMPLED, FORMAT = YEAR/MONTH/DAY/1.
MONTH AND DAY - A PORTION OF THE DATE OF OBSERVATION, FORMAT = MONTH/DAY.
ENDING FLOW RATE - RIVER DISCHARGE AT THE END OF A DOWNRAMP EVENT.
AMPLITUDE - AMPLITUDE FLUCTUATION BETWEEN THE FLOW AT THE BEGINNING AND THE END OF THE DOWNRAMP.
RAMPRATE - RAMPRATE CALCULATED AT THE INDICATED GAGE LOCATION.
HOURS OF DAYLIGHT - INDICATES WHEN DOWNRAMP ENDS IN RALATION TO SUNRISE.... NEGATIVE HOURS REPRESENT BEFORE, POSITIVE HOURS INDICATES AFTER SUNRISE.
FLOW HISTORY - NUMBER OF HOURS FLOW RATE WAS HELD CONSTANT PRIOR TO A DOWNRAMP EVENT.
GAGE - GAGE LOCATION USED TO DETERMINE FLOW RELATED PARAMETRS (N = NEWHALEM, AM = ALMA CREEK, AND M = MARBLEMOUNT).

GRAVEL BAR NAME	NUMBER OF STRANDED CHINOOK FRY	DATE OF OBSERVATION (YR/MO/DAY/1)	MONTH AND DAY	ENDING FLOW RATE (CFS)	AMPLITUDE OF DOWNRAMP (CFS)	RAMPRATE (CFS/HR)	HOURS OF DAYLIGHT (HRS)	FLOW HISTORY (HRS)	GAGE
MARBLE MT	8.50000	6903281	328	4400	2250.00	975.000	-2.00000	5.00000	M
MARBLE MT	8.10000	8003231	323	3610	2690.00	845.000	1.00000	3.00000	M
MARBLE MT	7.20000	8103261	326	3610	1990.00	870.000	1.00000	16.0000	M
MARBLE MT	6.30000	6903301	330	3610	3390.00	1570.00	-1.00000	9.00000	M
MARBLE MT	6.30000	7702231	223	3610	4140.00	625.000	-10.0000	0.00000	M
MARBLE MT	5.00000	8003301	330	3370	2930.00	515.000	2.00000	4.00000	M
MARBLE MT	3.90000	8003311	331	3370	1930.00	695.000	1.00000	14.0000	M
MARBLE MT	3.20000	7703101	310	3860	3890.00	1475.00	-1.50000	0.00000	M
MARBLE MT	3.10000	8204011	401	3860	3140.00	650.000	1.25000	14.0000	M
MARBLE MT	2.80000	8303271	327	3610	3040.00	720.000	0.00000	1.00000	M
MARBLE MT	2.20000	8003241	324	3610	3390.00	675.000	0.00000	9.00000	M
MARBLE MT	1.90000	8203301	330	3610	2340.00	845.000	-1.00000	15.0000	M
MARBLE MT	1.90000	8103241	324	3370	2230.00	845.000	1.00000	12.0000	M
MARBLE MT	1.70000	8304171	417	3610	2340.00	420.000	-3.50000	10.0000	M
MARBLE MT	1.70000	8303261	326	3610	2340.00	915.000	-3.00000	14.0000	M
MARBLE MT	1.40000	8203121	312	4120	2180.00	650.000	-1.50000	13.0000	M
MARBLE MT	1.40000	8203171	317	3860	2440.00	600.000	0.00000	15.0000	M
MARBLE MT	1.40000	8203191	319	3610	2340.00	870.000	0.00000	2.00000	M
MARBLE MT	1.10000	8304181	418	3860	2090.00	870.000	-2.50000	11.0000	M
MARBLE MT	0.80000	8203181	318	3610	2340.00	600.000	0.00000	2.00000	M
MARBLE MT	0.80000	8103311	331	3860	4290.00	900.000	2.00000	38.0000	M
MARBLE MT	0.80000	8204071	407	3610	2340.00	845.000	-2.75000	14.0000	M
MARBLE MT	0.80000	8203311	331	3610	2690.00	650.000	-2.00000	11.0000	M
MARBLE MT	0.60000	8103271	327	3370	2230.00	440.000	0.00000	11.0000	M
MARBLE MT	0.60000	8204021	402	3610	2340.00	915.000	-2.75000	13.0000	M
MARBLE MT	0.60000	8203101	310	4120	2180.00	440.000	-0.50000	4.00000	M
MARBLE MT	0.30000	8203111	311	4400	1900.00	500.000	-2.50000	12.0000	M
MARBLE MT	0.00000	8204081	408	3610	1990.00	965.000	1.25000	18.0000	M
MARBLE MT	0.00000	8004141	414	4400	1900.00	600.000	-0.75000	9.05000	M
MARBLE MT	0.00000	6903131	313	2910	3940.00	800.000	-2.00000	2.00000	AM
MARBLE MT	0.00000	8303201	320	3860	2090.00	720.000	1.00000	16.0000	M
MARBLE MT	0.00000	7604221	422	3960	3140.00	1075.00	-2.00000	3.00000	AM
MARBLE MT	0.00000	8303191	319	3860	4290.00	870.000	-3.00000	7.00000	M
MARBLE MT	0.00000	8103251	325	3610	1990.00	590.000	0.00000	8.00000	M

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GAGE - GAGE LOCATION USED TO DETERMINE FLOW RELATED PARAMETRS (N = NEWHALEM, AM = ALMA CREEK, AND M = MARBLEMOUNT).

GRAVEL BAR NAME	NUMBER OF STRANDED CHINOOK FRY	DATE OF OBSERVATION (YR/MO/DAY/1)	MONTH AND DAY	ENDING FLOW RATE (CFS)	AMPLITUDE OF DOWNRAMP (CFS)	RAMPRATE (CFS/HR)	HOURS OF DAYLIGHT (HRS)	FLOW HISTORY (HRS)	GAGE
MARBLE MT	0.00000	8004131	413	3610	1990.00	270.000	-0.75000	10.0000	M
MARBLE MT	0.00000	7003121	312	2750	4100.00	1220.00	-2.00000	2.00000	AM
ROCKPORT	142.000	7303181	318	1040	3970.00	1510.00	3.00000	12.0000	N
ROCKPORT	49.6000	7303171	317	2260	4140.00	1140.00	1.00000	0.00000	N
ROCKPORT	42.6000	7003131	313	1600	5250.00	1845.00	-1.00000	8.00000	AM
ROCKPORT	15.2000	8103241	324	3370	2230.00	845.000	4.00000	12.0000	M
ROCKPORT	14.0000	6903141	314	1730	3620.00	1050.00	1.00000	14.0000	AM
ROCKPORT	13.3000	8303271	327	3610	3040.00	720.000	3.00000	1.00000	M
ROCKPORT	11.9000	8203181	318	3610	2340.00	600.000	3.00000	2.00000	M
ROCKPORT	10.4000	8204081	408	3610	1990.00	965.000	4.25000	18.0000	M
ROCKPORT	10.0000	7703221	322	4700	3450.00	1225.00	5.00000	17.0000	M
ROCKPORT	8.10000	8103261	326	3610	1990.00	870.000	4.00000	16.0000	M
ROCKPORT	7.50000	8203301	330	3610	2340.00	845.000	2.00000	15.0000	M
ROCKPORT	7.10000	8303201	320	3860	2090.00	720.000	4.00000	16.0000	M
ROCKPORT	6.20000	8203191	319	3610	2340.00	870.000	3.00000	2.00000	M
ROCKPORT	5.00000	8203171	317	3860	2440.00	600.000	3.00000	15.0000	M
ROCKPORT	4.20000	8103251	325	3610	1990.00	590.000	3.00000	8.00000	M
ROCKPORT	4.00000	8203311	331	3610	2690.00	650.000	1.00000	11.0000	M
ROCKPORT	3.70000	8003241	324	3610	3390.00	675.000	3.00000	9.00000	M
ROCKPORT	3.50000	8003231	323	3610	2690.00	845.000	4.00000	3.00000	M
ROCKPORT	2.70000	6903131	313	2910	3940.00	800.000	1.00000	2.00000	AM
ROCKPORT	2.30000	8103271	327	3370	2230.00	440.000	3.00000	11.0000	M
ROCKPORT	2.10000	8203101	310	4120	2180.00	440.000	2.50000	4.00000	M
ROCKPORT	1.90000	8003311	331	3370	1930.00	695.000	4.00000	14.0000	M
ROCKPORT	1.50000	8303191	319	3860	4290.00	870.000	0.00000	7.00000	M
ROCKPORT	1.50000	8204071	407	3610	2340.00	845.000	0.25000	14.0000	M
ROCKPORT	1.00000	8103311	331	3860	4290.00	900.000	5.00000	38.0000	M
ROCKPORT	0.80000	8304171	417	3610	2340.00	420.000	-0.50000	80.0000	M
ROCKPORT	0.80000	8204011	401	3860	3140.00	650.000	4.25000	14.0000	M
ROCKPORT	0.80000	8004141	414	4400	1900.00	600.000	2.25000	9.05000	M
ROCKPORT	0.80000	8203121	312	4120	2180.00	650.000	1.50000	13.0000	M
ROCKPORT	0.60000	8003301	330	3370	2930.00	515.000	5.00000	4.00000	M
ROCKPORT	0.60000	8004131	413	3610	1990.00	270.000	2.25000	10.0000	M
ROCKPORT	0.60000	8304181	418	3860	2090.00	870.000	0.50000	11.0000	M

PARAMETER DEFINITIONS:

STRANDED CHINOOK - NUMBER OF CHINOOK FRY STRANDED ON 200 FEET OF GRAVEL BAR.
DATE OF OBSERVATION - DATE GRAVEL BAR WAS SAMPLED, FORMAT = YEAR/MONTH/DAY/1.
MONTH AND DAY - A PORTION OF THE DATE OF OBSERVATION, FORMAT = MONTH/DAY.
ENDING FLOW RATE - RIVER DISCHARGE AT THE END OF A DOWNRAMP EVENT.
AMPLITUDE - AMPLITUDE FLUCTUATION BETWEEN THE FLOW AT THE BEGINNING AND THE END OF THE DOWNRAMP.
RAMPRATE - RAMPRATE CALCULATED AT THE INDICATED GAGE LOCATION.
HOURS OF DAYLIGHT - INDICATES WHEN DOWNRAMP ENDS IN RALATION TO SUNRISE.... NEGATIVE HOURS REPRESENT BEFORE, POSITIVE HOURS INDICATES AFTER SUNRISE.
FLOW HISTORY - NUMBER OF HOURS FLOW RATE WAS HELD CONSTANT PRIOR TO A DOWNRAMP EVENT.
GAGE - GAGE LOCATION USED TO DETERMINE FLOW RELATED PARAMETRS (N = NEWHALEM, AM = ALMA CREEK, AND M = MARBLEMOUNT).

GRAVEL BAR NAME	NUMBER OF STRANDED CHINOOK FRY	DATE OF OBSERVATION (YR/MO/DAY/1)	MONTH AND DAY	ENDING FLOW RATE (CFS)	AMPLITUDE OF DOWNRAMP (CFS)	RAMPRATE (CFS/HR)	HOURS OF DAYLIGHT (HRS)	FLOW HISTORY (HRS)	GAGE
ROCKPORT	0.40000	8303261	326	3610	2340.00	915.000	0.00000	14.0000	M
ROCKPORT	0.20000	8204021	402	3610	2340.00	915.000	0.25000	13.0000	M
ROCKPORT	0.00000	6903291	329	3610	3040.00	1395.00	2.00000	9.00000	M
ROCKPORT	0.00000	7703191	319	3860	3490.00	1090.00	3.00000	1.05000	M
ROCKPORT	0.00000	8203111	311	4400	1900.00	500.000	0.50000	12.0000	M
ROCKPORT	0.00000	7003071	307	2140	4960.00	2015.00	1.00000	48.0000	AM
ROCKPORT	0.00000	6903301	330	3610	3390.00	1570.00	2.00000	9.00000	M
ROCKPORT	0.00000	7602051	205	3970	2640.00	515.000	-1.00000	16.0000	N
ROCKPORT	0.00000	6903281	328	4400	2250.00	975.000	1.00000	5.00000	M
SUTTER CR	1.00000	7303181	318	1040	3970.00	1510.00	3.00000	12.0000	N
SUTTER CR	0.70000	7303171	317	2260	4140.00	1140.00	1.00000	0.00000	N
THORTON CR	1.40000	8203101	310	2370	2110.00	435.000	-2.50000	5.00000	N
THORTON CR	1.10000	8203301	330	2370	2280.00	1140.00	-3.00000	16.0000	N
THORTON CR	0.80000	8203311	331	2370	2830.00	705.000	-4.00000	12.0000	N
THORTON CR	0.80000	8103271	327	2260	2220.00	450.000	-2.00000	13.0000	N
THORTON CR	0.60000	8103241	324	2260	2390.00	1080.00	-1.00000	13.0000	N
THORTON CR	0.30000	8203171	317	2370	2640.00	835.000	-3.00000	15.0000	N
THORTON CR	0.30000	8103261	326	2370	2280.00	970.000	-1.00000	16.0000	N
THORTON CR	0.30000	8203121	312	2370	2280.00	665.000	-3.50000	13.0000	N
THORTON CR	0.30000	8103251	325	2260	2390.00	875.000	-2.00000	7.00000	N
THORTON CR	0.00000	8203111	311	2370	2280.00	580.000	-4.50000	13.0000	N
THORTON CR	0.00000	8103311	331	2260	4560.00	1185.00	0.00000	39.0000	N
THORTON CR	0.00000	8203181	318	2370	2280.00	815.000	-3.00000	1.00000	N
THORTON CR	0.00000	8203191	319	2370	2280.00	1140.00	-3.00000	2.00000	N
THORTON CR	0.00000	8204021	402	2370	2280.00	1195.00	-4.75000	14.0000	N
THORTON CR	0.00000	8204011	401	2370	1450.00	545.000	-0.75000	1.00000	N
WASHINGTON ED	0.00000	7003071	307	2140	4960.00	2015.00	-2.00000	48.0000	AM

PARAMETER DEFINITIONS:

STRANDED CHINOOK - NUMBER OF CHINOOK FRY STRANDED ON 200 FEET OF GRAVEL BAR.
DATE OF OBSERVATION - DATE GRAVEL BAR WAS SAMPLED, FORMAT = YEAR/MONTH/DAY/1.
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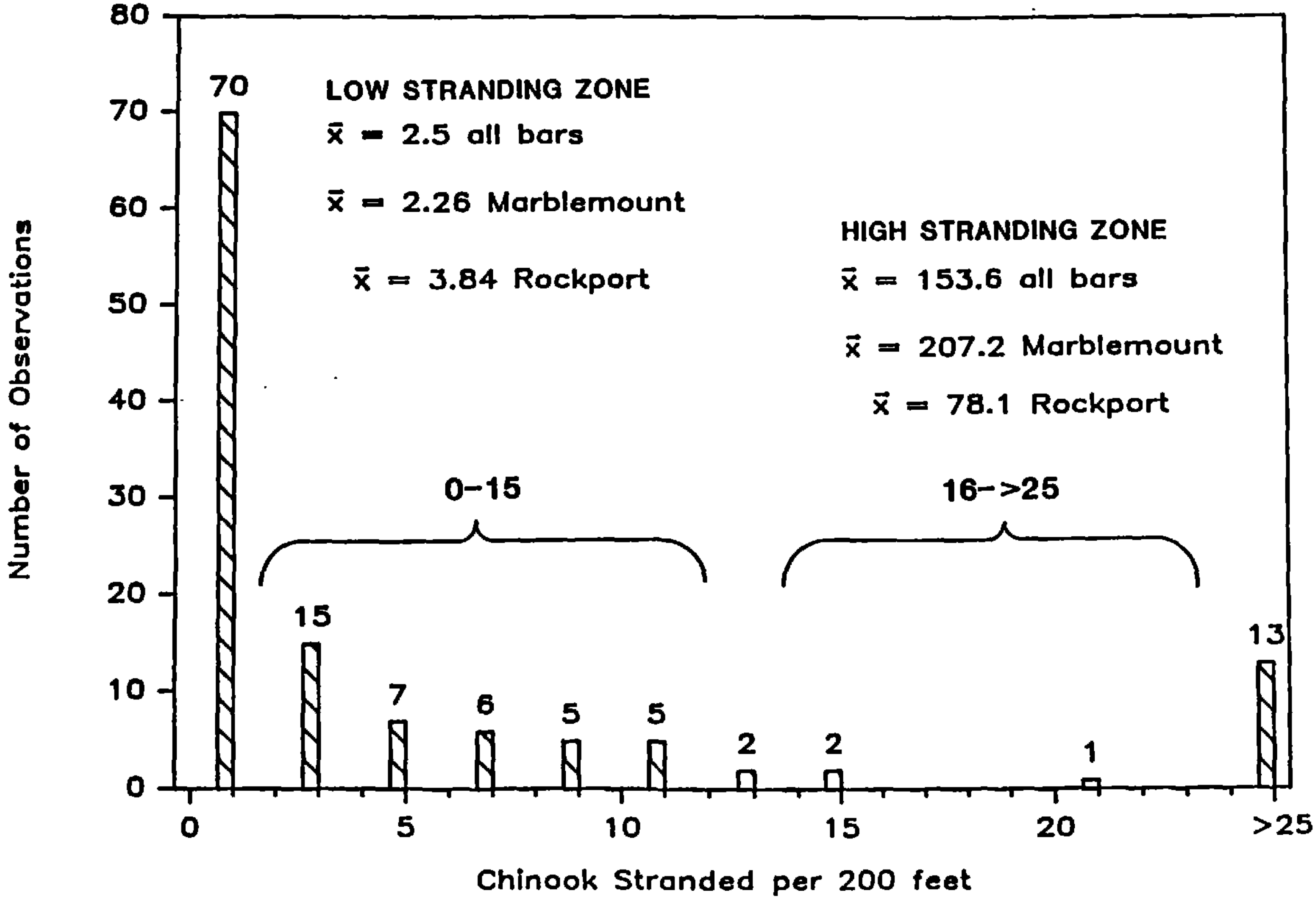
FLOW HISTORY - NUMBER OF HOURS FLOW RATE WAS HELD CONSTANT PRIOR TO A DOWNRAMP EVENT.
GAGE - GAGE LOCATION USED TO DETERMINE FLOW RELATED PARAMETRS (N = NEWHALEM, AM = ALMA CREEK, AND M = MARBLEMOUNT).

note: Washington Ed is equivalent to Eagle Bar

FIGURE 51
CHINOOK FRY GRAVEL BAR STRANDING FREQUENCIES
FROM SKAGIT RIVER STUDIES, 1969-83



happened within one hour of sunrise and the third level having downramps that happened at least one hour or more after sunrise. Finally, only Rockport and Marblemount gravel bar data were used in the study design matrix to reduce gravel bar site variability.

This matrix, which contains 36 cell combinations, had only two cells within which both Rockport and Marblemount had more than one replicate (Table 46). Thirteen of the cells had no observations at either gravel bar site. Reduced study design combinations typically resulted in an unbalanced design and a lack of observations (replicates). The only exception to this was a pair-wise test of the effect of daylight versus darkness downramping which is discussed below.

Because of the clear deficiencies in the study design matrix the effects of endflow, ramping rate, amplitude, and gravel bar cannot be determined statistically. It should be pointed out that statistical tests such as Mann-Whitney, and ANOVA's were attempted but were not successful for the same reasons discussed above. Although this database did not meet the requirements of rigid statistical testing it did provide R. W. Beck and Associates with valuable insight that was used to build a strong study design for our work. It should also be pointed out the failure of this database was no fault of the past researchers since the data were never intended to be used in combination.

Ten pairs of day versus night tests were conducted during March and April of 1981-83 at Marblemount and Rockport gravel bars on the Skagit River. Each pair of tests consisted of a daylight and darkness downramping event. All testing variables such as downramping amplitude, endflow, and ramping rates were held relatively constant. Each pair of tests was conducted on successive dates so as to minimize any time related influence on fry stranding numbers. In addition, the first two test pairs had the daylight downramp first followed by the darkness downramp the next day. The final three test pairs reversed the order with darkness followed by daylight. These experimental design considerations were used to test for any difference between fry stranding resulting from daylight versus darkness downramping, which was used as the dependent variable in the experimental design.

Table 47 shows the test parameters and results of the day versus night downramping tests conducted between 1981-83 on the Skagit River at Marblemount and Rockport Bars.

The results of a Wilcoxon Signed-Ranks Test on daylight versus darkness fry stranding are shown in Table 48. Among the nine varied observations the daylight stranding was always greater resulting in a P-value less than 0.01 leading to the conclusion that chinook fry are more likely to become stranded during daylight downramping.

The results of this work appear to indicate that more stranding occurs with daylight downramping. Pair-wise comparison of the data in Table 47 from each of the two gravel bar sites shows that Marblemount daylight stranding was on the average eight times higher than for darkness downramping. These daylight stranding values at Marblemount ranged from 1.4 to 12.6 times the number of fry stranded during each pair's associated darkness downramp. Rockport results were

TABLE 46

MATRIX SHOWING THE DISTRIBUTION OF GRAVEL BAR STRANDING TEST OBSERVATIONS AT MARBLEMOUNT AND ROCKPORT BARS FOR SEVERAL LEVELS OF FOUR TESTING VARIABLES BETWEEN 1969 AND 1983 BY VARIOUS RESEARCHERS

		HOURS/DAY PREDAWN		HOURS/DAY DAWN		HOURS/DAY DAYLIGHT	
		AMP <3000	AMP >3000	AMP <3000	AMP >3000	AMP <3000	AMP >3000
ENDFLOW <3000	RAMPRATE <1000	M-0 R-0	M-0 R-1	M-0 R-0	M-1 R-0	M-0 R-0	M-0 R-0
	RAMPRATE >1000	M-0 R-0	M-1 R-6	M-0 R-0	M-3 R-0	M-0 R-0	M-0 R-0
ENDFLOW [3000, 3600)	RAMPRATE <1000	M-0 R-6	M-0 R-1	M-5 R-11	M-0 R-1	M-13 R-1	M-1 R-0
	RAMPRATE >1000	M-0 R-0	M-1 R-1	M-0 R-1	M-0 R-1	M-1 R-0	M-1 R-0
ENDFLOW >3600	RAMPRATE <1000	M-1 R-4	M-0 R-0	M-3 R-3	M-1 R-0	M-6 R-1	M-1 R-1
	RAMPRATE >1000	M-0 R-1	M-0 R-1	M-0 R-0	M-0 R-0	M-0 R-0	M-2 R-1

M = MARBLEMOUNT

R = ROCKPORT

very similar; the average stranding factor was 7.2 times higher and the individual pair comparisons ranged from 3.2 to 14.5 times higher than the number stranded during darkness downramp. Rockport results were very similar; the average stranding factor was 7.2 times higher and the individual pair comparisons ranged from 3.2 to 14.5 times higher than the number stranded during darkness downramp.

TABLE 47

TESTING PARAMETER AND RESULT SUMMARY TABLE FOR DAY VERSUS NIGHT DOWNRAMPING TESTS CONDUCTED BY WASHINGTON STATE DEPARTMENT OF FISHERIES (WOODIN, 1984) DURING MARCH-APRIL OF 1981-83 ON THE SKAGIT RIVER AT MARBLEMOUNT AND ROCKPORT BARS

	Downramp Parameters Measured at Marblemount				Fry Stranded	
Test Date	Amplitude (cfs)	Endflow (cfs)	Ramping Rate (cfs/hour)	Time (Day/Night)	Marblemount	Rockport
3/26/81	1990	3,610	870	Day	26	49
3/27/81	2230	3,370	440	Night	2	15
4/1/82	3,140	3,860	650	Day	11	62
4/2/82	2,340	3,610	915	Night	2	9
4/7/82	2,340	3,610	845	Night	3	15
4/8/82	1,990	3,610	965	Day	38	98
3/19/83	4,290	3,860	870	Night	--	7
3/20/83	2,090	3,860	720	Day	26	36
3/26/83	2,340	3,610	915	Night	7	9
3/27/83	3,040	3,610	720	Day	10	131

TABLE 48

RESULTS OF A WILCOXON SIGNED-RANKS TEST
USING NINE PAIRED DAY VERSUS NIGHT
FRY STRANDING OBSERVATIONS

Dependent Variables	Observations	Mean Fry Stranded	S.D. Diff.	T (P-Val)		Signed Ranks +	Signed Ranks -	Tie	Z (P-Val)
NIGHT		7.667			N	0	9	0	
	9		37.743	3.46	Mean				2.67
DAY		51.222		(.0086)	Rank	0.000	5.000		(.0077)

SECTION VIII

DISCUSSION

1. GENERAL

The primary goal of this discussion is to review what has been learned and what is known about pothole trapping and stranding and gravel bar stranding of salmonid fry on the Skagit River. This review and discussion shall deal with each of the three areas of study separately: pothole trapping and stranding, gravel bar stranding of salmon fry, and gravel bar stranding of steelhead fry.

2. POTHOLE TRAPPING AND STRANDING

a. Pothole Mechanism

The phenomenon of pothole fry trapping and stranding has been defined as two very distinct processes. The first process is when fry become trapped in potholes. For trapping to occur the fry must not only be present in or near pothole habitat but the river stage must be lowered for connected potholes to trap fry by becoming disconnected from the main-channel flow. Hours of observation and the results of electroshocking seemed to indicate that most newly emerged fry species when present in main-channel habitat are found near waters-edge in the shallower, slower velocity habitat. The waters-edge habitat moves dynamically on a daily basis as controlled by weather and operation of the powerhouse at Newhalem. Fry are constantly subjected to stage changes that force them to move with the waterline if they wish to remain in waters-edge habitat. On many occasions fry were observed moving into and out of potholes that were located at waters-edge where velocities were near zero and water depths varied. On several occasions a school of fry were chased out of the pothole into the main channel only to watch them move back into the pothole within a few minutes. These observations of salmon fry supports the idea that fry may seek out pothole habitat when it is available along the waters-edge habitat. Troutt's results also showed that chinook fry do remain in specific potholes for longer than a complete upramp to upramp cycle. If potholes are preferred by salmon fry, what kinds of hydraulic factors play a role in fry becoming trapped in potholes? Prior to a specified downramping event, three types of potholes can be identified: (1) potholes that begin the downramp event disconnected from the main river channel flow, (2) potholes that are connected to the main river channel flow by only a few inches of water, and (3) potholes that are submerged by a large amount of main-channel flow. Each of these pothole types presents itself to fry differently during a downramping event. The first pothole type remains disconnected from the main-channel flow throughout the entire downramping event. These potholes do not affect free-swimming fry since there is no opportunity for them to become trapped since these potholes were never connected to the river. However, these potholes may contain trapped fry from an earlier downramping event that started at a higher beginning flow. These fry were not trapped as a result of the downramp scenario described in the above example.

The second type of pothole mentioned above are those that begin the downramping event connected and very near waters-edge. These potholes provide fry with the maximum time to find and occupy them since they are near waters--edge in slower velocity areas. Some of these potholes remain hydrologically unchanged (maintain stable flow and depth characteristics) for many hours before a downramp takes place. For this reason fry have ample opportunity to find and occupy a pothole because the recruitment time is so long compared to other pothole types. Once fry have moved into these potholes a downramp is all that is required to trap them. Many of these fry move into potholes as the waterline moves up the gravel bar from the previous upramp and may remain in the pothole for a number of hours before a downramp occurs. These fry have very little time or warning about a downramp, unlike fry that might try to locate potholes while a downramp is occurring.

The third pothole type, those submerged by a substantial amount of water, begin the downramp away from the waters-edge, perhaps out of habitat preferred by fry. During the downramping event, these potholes may remain connected to the flow in the main channel or will disconnect. Potholes that remain connected do not effect fry adversely since the fry never become trapped and subsequently cannot become stranded. Depending on the speed of stage change, potholes that do become disconnected provide preferred habitat for fry for a short time as the waterline continues on past the pothole's position on the gravel bar. It is during this time that fry may locate a pothole and elect to remain there as the waterline continues to recede. Once the pothole becomes disconnected from main-channel flow the trapping process is complete.

The second process in this mechanism is stranding of fry in potholes. Fry stranding typically occurs when a disconnected pothole drains until dry. Most stranding observed occurred in potholes that were essentially dewatered. Each pothole has a dry flow associated with it which roughly determines when that pothole will go dry. When main-channel flow approaches this dry flow it is very likely that any fry trapped in the pothole will become stranded. Once the pothole has gone dry there is presumed to be no avenue of escape for trapped fry other than to move down into the gravel, which would be difficult with some substrate types and unlikely.

b. Factors Affecting Fry Trapping And Stranding

The most significant factor affecting fry trapping in any given pothole is the beginning flow of a downramp event. The beginning flow determines the depth of water over a pothole while simultaneously determining the pothole's distance from waters-edge. Typically the higher the beginning flow, the further from waters-edge the pothole is located.

Fry, especially newly emerged, prefer slow velocity, shallow habitat that is most prevalent along waters-edge. If a pothole is covered by two feet of water, it is unlikely to be located at waters-edge and probably does not offer the type of habitat preferred by fry. Therefore, when a large number of potholes with a history of trapping fry are located at and remain near waters-edge, the probability of trapping large numbers of fry is much greater than when these same potholes remain disconnected or alternatively are covered by a substantial amount of water. In the later case fry moving across the gravel bar with waters-edge during a typical downramp have only a short time to first locate and second occupy a pothole as it develops on the receding waters-edge habitat. On the other hand, if a large number of potholes are located at waters-edge prior to a downramp, fry have more and longer opportunities to encounter and occupy this habitat before the downramp begins. The relationship between pothole overflow and beginning flow provides the strongest and most understandable explanation of the trapping mechanism. It is important to understand that the critical beginning flows (4,500 to 5,500 cfs) in Figure 13 also coincide with most of the connection flows for potholes with a history of trapping and stranding fry as shown in Figure 7. When downramp beginning flows are between 4,500 and 5,500 cfs the highest numbers of potholes are found at waters edge offering fry many opportunities to occupy potholes. Not only are many more potholes available for fry occupation at this range of beginning flows but they are available for longer periods of time than potholes that are submerged at the start of a downramp. Prior to a downramp the water level may not change for hours at a time. A pothole at waters-edge will have a much longer time to recruit fry than a pothole that begins a downramp event submerged. The submerged pothole will be available for recruitment for only a short while depending on how fast the waterline recedes, which is controlled by the downramping rate.

Another important factor that is associated with beginning flow and fry trapping is the beginning flow history (see Appendix A). If downramp beginning flows in the 4,500 to 5,500 cfs range are repeated in series, the number of fry trapped in potholes increases after each successive downramp (See Figure 49). If the same process is repeated followed by a downramp with higher level of flow (e.g., 7,000-7,500 cfs), the fry trapped in potholes is unpredictable and generally remains moderately low. A logical explanation for this, and one that follows the previous discussion, is that high beginning flows create unacceptable pothole rearing conditions so fry move out of potholes so that they can remain in or near waters-edge habitat. Conversely, low beginning flows encourage fry to seek out pothole habitat since these beginning flows coincide with a large number of pothole connection flows. When low beginning flows are repeated, fry numbers increase as fry already present take up residence between downramps and other fry become newly recruited. This process is more than likely interrupted by a high downramp beginning flow which flushes fry from potholes, starting the process over again.

Troutt's study of fry residency times in potholes introduces several interesting factors that affect fry trapping in potholes. Troutt's results clearly indicate that some fry will remain in potholes between downramps, or return to the pothole after leaving between downramps. The study data could not be used to determine if fry remain in the pothole or move back and forth between downramps. The study did, however, demonstrate that some fry will remain in or return to potholes after becoming trapped the first time. Thus for a series of downramp events some fry become trapped for the first time while others are trapped repeatedly.

His data indicate that pothole cover and substrate complexity parameters also influence the residency time of fry found in potholes. Potholes with cover and larger more complex substrate extended the residency times of certain fry species.

Ladley's (1986) study of fry recruitment into empty potholes, simulating potholes that have gone dry, also revealed some interesting results especially regarding beginning flow history patterns. The study initially set out to determine how long (pothole connect/disconnect cycles) it would take for fry to recruit into empty potholes once fry had been removed from them. The study also attempted to determine what factors might influence the rate or magnitude of fry recruitment.

The results of Ladley's data analysis indicates that fry recruitment occurs during the first downramp following a connection flow. This result was not surprising given the relative mobility of most fry species. After the first connection flow the only apparent pattern to fry recruitment occurs when low range (4,500 - 5,500 cfs) beginning flows are repeated. When this condition takes place, fry recruitment increase after each downramp until a higher range beginning flow interupts the pattern.

The dryflow of a pothole is the major factor influencing stranding. Once a fry is trapped inside a pothole, stranding is determined by the endflow of the downramp event. If the endflow falls below the dry flow of pothole it will likely go dry, stranding the fry within it. This is a very simplistic description of a complex process since the effect of a given down ramp endflow is influenced by a number of other factors that are well beyond the scope and understanding of this study. Some of these factors are tributary inflow, bank storage, and how long the endflow is maintained.

In most circumstances, however, a pothole will go dry or close to dry when the endflow falls below the dry flow of a pothole. Marblemount flows were used as a standard for measuring connection and dry flows in the study area. There are also a few potholes that have two pools within them, each with a different elevation so that one pool may go dry while the other retains water. Fry in the dewatered half will strand while fry in the other half will remain trapped.

Trapped fry can fall victim to other factors such as predation and elevated water temperatures. Predation by birds or small mammals is a form of pothole mortality that occurs on both controlled and uncontrolled streams possessing potholes. While certainly a cause of some mortality, it is felt to be minor in terms of contribution to total pothole mortality. Elevated pothole water temperature is another possible source of pothole mortality. Water temperatures in potholes may reach harmful levels if prolonged exposure occurs when air temperatures are high. This factor was monitored during the spring 1985 pothole trapping and stranding study. Trapped fry were never observed in a destressed state, or dead as a result of elevated water temperatures.

c. Magnitude of Pothole Trapping And Stranding

Our studies produced quantitative data for the spring months on pothole trapping and stranding of salmon fry in the Skagit River between Copper Creek (River Mile 84.0) and Rockport (River Mile 67.5). These data represent the number of fry stranded in the 232 potholes located in this stream reach and within the range of observed operational flows (3,000 - 6,000 cfs). These results are affected by the size of the fry population and the population of potholes present in the spring of 1985. The data do not account for potholes located between Copper Creek and Newhalem. Earlier pothole reconnaissance surveys by Jones and Stokes, Inc. in November of 1984 found 67 high-flow potholes (Gorge Release = 7,000 cfs) but did not conduct surveys at lower release flows for low to mid-flow potholes. Without question there are potholes in the upper reach that would contribute stranded fry to the total number of fry stranded for the spring vulnerability period. With this exception, the number of trapped and stranded fry predicted for each of six flow scenarios is complete. Several other things should be kept in perspective when using the matrix. First, the matrix was constructed from data collected primarily from the spring of 1985. Adult escapement from the previous fall and egg-to-fry survival was assumed to be average rather than high or low. Fry composition and abundance were probably very typical for a non-pink return year. The implications are that the matrix predictions represent an average fry abundance and would have to be adjusted accordingly for a low or high abundance year. A second consideration is that the predictive matrix is from a set of potholes that is temporally dynamic. Potholes are constantly changing in location, size, and physical make-up especially during highwater events. For example several potholes that stranded fry during the spring 1985 study were no longer present by the following spring. Others had changed with respect to size, depth, substrate, or cover availability. The predictive matrix accurately predicts fry stranding with a given flow type during 1985, but should not be used without adjustments for other years unless certain assumptions are accepted. For example, it may be theorized that for every 1985 pothole that disappears another is formed to take its place in the matrix. Perhaps in five years time the 226 potholes represented in the matrix may have all been replaced but the magnitude of the number of fry trapped and stranded may not have changed dramatically given an average fry abundance year and that operational trends have not changed significantly. The matrix does not account for two other possible sources of error; observer error during the field study and predation on fry trapped or stranded in potholes. With this in mind it is possible to determine and understand within some limits of precision the magnitude of the pothole stranding problem for the spring season. Quantitative pothole trapping and stranding data was not collected during the July-September field season so the magnitude of the pothole stranding problem could not be determined. Some observations were made of trapped and stranded fry in potholes (see Pothole Residence Study Appendix E).

To determine the magnitude of the pothole stranding problem it was necessary to sum the number of fry stranded for each day of operation during the 120-day period of vulnerability. Since the matrix could only provide estimates for six different flow patterns it could not be used in the above application since Gorge Powerhouse releases vary daily. The approach used involved taking the highest level of stranding identified by the matrix (76.5 stranded) multiplied by 120 days which is the period of vulnerability, to arrive at a number representing the relative magnitude of fry stranding in potholes for the spring time period between Copper Creek and Rockport. Within the limits of the study, this index would tend to over-estimate stranding because it uses a high-side approximation approach which conservatively assumes that fry abundance remains constant throughout the vulnerable period which it does not and that daily Gorge Powerhouse operations create the same large amplitude fluctuation for 120 consecutive days which does not occur. This approach estimates that a total of 9,180 salmon fry would be stranded during a typical spring vulnerability period. Nearly all of these fry were presumed to be chinook fry. The species composition of fry found in potholes during the spring months was almost exclusively chinook. Ninety-eight percent of the 3,006 fry sampled during Ladley's study were chinook. (See Table 43.) Ninety-four percent of the 304 fry sampled in potholes during the spring, 1986 fry gravel bar stranding tests were also chinook. (See Table 26.)

3. GRAVEL BAR STRANDING

a. Gravel Bar Stranding Mechanism

When the river is upramped the waters-edge moves up the gravel bar, and it is presumed the fry move with it to remain in preferred habitat. This upramping process in itself does not create any problems for the fry since they can follow the waterline as it moves. If for some reason an individual fry decides not to follow the progress of the waterline, at worst it finds itself in habitat that is both deeper and faster which may exhaust it but certainly does not normally create a lethal situation since it can move to waters-edge at any time. On the other hand a downramping event can lead to fry stranding due to a fry's inability to adjust to a change in the waters-edge. The waters-edge habitat moves at different speeds depending on the gravel bar slope, the ramp rate, and the total amplitude fluctuation of a downramping event. The faster the ramp rate the quicker the waters-edge moves and the larger the amplitude fluctuation the farther a fry must move to avoid stranding. On any particular gravel bar there are many more fry at risk than become stranded. Only a very small percentage of those fry present actually end up stranded during any particular downramping event. That is to say that most of the time the "average" fry makes the right decisions to avoid gravel bar stranding and that it is the odd fry that becomes stranded because it employs a different behavioral response (makes a wrong decision) to a downramp event. Our results also indicate that fry stranding is not a contagious behavior since most of the fry stranded did not strand in groups but were distributed in a random fashion on most bars.

b. Summer/Fall Gravel Bar Stranding

(1) Species Vulnerability

During the summer months of July through October there are only two species of fry present in significant numbers within the project study area. Steelhead fry appear to be the most abundant and were found inhabiting all types of habitat available to them for rearing purposes. On the other hand coho, while abundant, were found almost entirely in back-channel and pothole habitat and only very rarely in main-channel gravel bar stranding habitat. The results of electroshocking in main-channel habitat support this finding with nearly 98% of the fry captured in this habitat being steelhead fry. (See Table 12.)

Not only did coho not inhabit gravel bar stranding habitat they also represented less than 1% of the total number of fry stranded during the study. (See Table 12.) Coho when present in gravel bar stranding habitat appear to be relatively invulnerable to gravel bar stranding as suggested by the difference between their percent contribution to the species composition (2.6%) and stranding (0.8%).

Steelhead fry on the other hand dominated habitat along gravel bars that are typically dewatered during downramping events. They also represented more than 99% of fry stranded on gravel bars during the summer-fall period. It is clear from these data that steelhead fry are stranded in much higher numbers than coho. The data suggest that because steelhead fry occupy main-channel riffle habitat, which commonly covers many of the gravel bar areas studied, they become susceptible to gravel bar stranding. Conversely, coho fry do not use main-channel habitat and as a result are more infrequently affected by gravel bar stranding then steelhead fry.

(2) Size Of Vulnerability

Steelhead fry gravel bar stranding is size dependent. A comparison of steelhead fry size, frequency distribution of fry sampled from the general population present in gravel bar habitat vs. fry stranded revealed that smaller lengths (i.e., fry that have just emerged from the gravel - approximately 3.0 to 3.5 centimeters) were much more frequent among stranded fry. By the time fry reach a total length of 4.5 centimeters in total length, their apparent vulnerability is noticeably reduced. Beyond this length, stranding is probably a rare event as evidenced by the small number of steelhead juveniles that were observed stranded on gravel bars the following spring. (See Section VI.)

(3) Time Of Vulnerability

It appears that fry of the most vulnerable size are present from July 1 to September 30. Before this time most of the fry are still beneath the gravel or are not easily visible along the waters-edge, back-channels or potholes as evidenced by the surveys completed prior to the first gravel bar stranding test. After this time period most of the steelhead fry have exceeded the most vulnerable size. It seems apparent that after this peak vulnerability period few fish are stranded.

(4) Physical And Hydrologic Factors

As would be expected the sensitivity to flow fluctuations were more accentuated higher upstream and for less steep gravel bars. Under these conditions statistically significant effects were demonstrated for the factors; bar slope, river reach, substrate size, and downramp amplitude. Over the range tested, stranding increased proportionately with amplitude. Additional studies were completed to explore any relationships between physical features on gravel bars and stranding location of fry. The following discusses each of these factors separately.

This analysis has by no means explored all hypothesis or models that might be conceived regarding steelhead fry gravel bar stranding. The large database collected in 1985 is fertile ground for further growth of our understanding of steelhead fry behavior in response to flow fluctuations.

(a) Amplitude

Fry stranding on gravel bars was significantly higher with a 4,000 cfs downramp than with 2,000 cfs (Figure 25 and Table 18). The 4,000-cfs amplitude stranded more than twice the number of fry stranded by the 2,000-cfs amplitude fluctuation. There was also a tendency for fry to become stranded towards the end of a downramping event. This tendency was stronger for a large amplitude than a small amplitude event. It is not clear why stranding would occur more frequently near the end of a downramping event especially a large amplitude event. It perhaps may be linked to some hydrologic changes that happen near the end of a downramp as river stage tries to reach an equilibrium.

(b) Downramping Rate

The analysis of variance tests (Table 17, Figure 26) failed to show a significant effect due to three ramping rates tested. Ramping rates between 1,000 and 5,000 cfs/hr appear to have virtually the same effect on the number of fry ultimately stranded. In fact it appears that for steelhead fry it makes little difference what ramping rate is used within this range.

More interestingly, a closer examination of the accelerated ramping rate showed that fewer fry were stranded during the 500 cfs/hr phase than 5,000 cfs/hr phase. Since complete downramping events using 500-1,000 cfs/hr were not tested and since most stranding occurs toward the end of an event, it is unknown what effect rates within this range might be. It is possible that a threshold level is reached below which the rate of stranding is reduced and above which the rate of stranding remains relatively constant. If such a critical ramping rate exists, our study indicates that the rate is somewhere below 1,000 cfs/hr.

(c) Gravel Bar Slope

Three levels of gravel bar slope were tested (0-5%, 5-10%, and greater than 10%) and a very significant relationship was discovered (Table 18 and Figure 27). The smaller the gravel bar slope the higher the rate of stranding. In fact, it appears that gravel bar slopes between 0-5% are most critical as demonstrated by the results of this study where more than 80% of the fry stranded were on gravel bars with slopes less than 5%.

The gravel bar slope was the factor which most significantly influenced gravel bar stranding. In our inventory of the Skagit River above Rockport, we estimated that 10,100 out of 29,110 lineal feet of gravel bar had a slope less than 5%. It is likely that this number changes with flow (perhaps more small slope area is involved when the river channel is fuller). However, it is not known whether these changes are significant. The concept of managing the amount of gentle slope gravel bar dewatered by controlling beginning flows was not investigated. The gravel bar slope influences the rate at which a gravel bar becomes dewatered. For a given downramping amplitude and ramp rate dewatering of gravel bar habitat will occur much more rapidly on gravel bars with gradual than steep slopes since the water surface elevation must travel farther on a gradual slope than a steep one to reach the same stage. Clearly the rate of dewatering (in terms of square feet of gravel bar per unit time) and the area dewatered increases as slope decreases. Thus, hydrological effects are more exaggerated. Therefore, if fry stranding is sensitive to downramp amplitude and rate this should be more evident on bars with gentle slopes than on steep ones. Two conclusions can be drawn from the observed effects of slope on fry stranding. First, more fry are stranded on gravel bars with a gradient of less than 5% than those with a greater slope under any hydrological conditions. Secondly, the sensitivity of fry stranding to hydrological factors is greater on small slopes. It is important in this context to also keep in mind the observation that gravel bar stranding tends to increase toward the end of the event (at least in certain circumstances) suggesting that there are behavioral and/or hydrological complications not accounted for in a simple linear rate model.

(d) River Location

The location of the gravel bar on the river with respect to the source of the flow fluctuation (in this case Gorge Powerhouse) has a strong bearing on the effect of any downramping event (Table 18 and Figure 28). The location and amount of tributary inflow also affects the strength of a downramping event. A combination of distance and inflow is capable of masking or moderating the effects of a downramp event despite the severity of the event.

This relationship was apparent throughout the results of the various testing factors. In almost all cases the stranding rate was greater in the middle stream reach where the relative volume of water involved in a downramp is greater as compared to the lower reach where tributary inflow and distance combine to dampen the impact of downramping. This process is explained in more detail in Section II - Hydrology of the Skagit River.

(e) Substrate

The ANOVA rates substrate as significant (Table 17 and Figure 29). Smaller substrate tended to strand more fry than coarse. However, some reverse effects were obvious such as the possible reverse interactions between gravel bar slope and substrate size. These interactions were not readily explainable but should be noted. For example, in Figure 29 gravel bars with slopes of 0-5% had more fry stranded on them when large substrate (greater than 3 inch) was present than with small substrate (less than 3 inch); 7.89 fry per 200 feet of bar versus 4.60 fry per 200 feet respectively. This relationship reverses on gravel bars with slopes of 5-10% with large substrate stranding less fry than small substrate (0.51 versus 2.46 fry per 200 feet of gravel bar).

These results are perhaps understandable using the following logic. A fry to avoid stranding must travel much further to escape on a gentle slope gravel bar then on steeper bars. If the bar has large substrate it will present the fry with a far more complex maze through which it must escape versus a similar gravel bar with fine substrate. The larger the downramp amplitude the longer the escape route and the more adjustments a fry must make as the waterline slowly recedes. The more decisions (adjustments) to be made with a complex substrate (large substrate) the higher the probability of making a bad decision resulting in stranding. Using the same example with a less complex substrate (small substrate), the fry must travel the same distance to escape but the number of decisions will likely be reduced which in turn lowers the probability of stranding.

Steep gravel bar slopes had higher stranding rates with small substrate than large substrate. This is the opposite response observed with gentle slope gravel bars. First, note that stranding rates were considerably higher on gentle slope gravel bars versus steep (4.60-7.89 vs .51-2.46). This in part may be the result of fry density which is likely to be controlled by habitat suitability and also that the width of bar dewatered is much smaller on a steeper bar. Velocity is perhaps an over-riding factor which influences the presence or absence of fry in various habitat types. If the velocity is too high fry will not be able to remain in the habitat. Perhaps on steep-sided gravel bars with large substrate which indicates high velocities, fry can not occupy the habitat because energy consumption is too great or they can not physically overcome the velocity requirements needed to maintain position. While on steep-sided gravel bars with small substrate the velocity is within a suitable range allowing fry to occupy the habitat and be at risk to gravel bar stranding. This provides an explanation which in general makes sense biologically and hydrologically.

(f) <u>Daylight vs. Night Downramping</u>

The average number of fry stranded during the night tests was slightly higher than for daylight downramping tests but there was no significant difference between the transformed or untransformed data. These data clearly suggest that daylight downramping does not increase steelhead fry stranding on gravel bars. There was virtually no difference between daylight versus darkness downramping on steelhead fry. This finding is particulary interesting since daylight downramping has been shown to strand significantly more salmon fry than darkness downramping. No logical explanation for this could be developed.

(g) <u>Fry Stranding Locations vs. Gravel Bar Features</u>

With the exception of potholes and channel depressions, which functioned as oversized potholes, there was no relationship between the stranding locations of fry and definable gravel bar features including; logs, wood debris piles, large rocks, vegetation lines, auto part debris, or channel depressions. It appears that fry do not strand in or around obvious bar features, that when submerged, may function as cover sources.

(5) Magnitude of Steelhead Fry Gravel Bar Stranding

Within the limits of the study, the "high side" steelhead fry stranding calculation, assuming a peak vulnerability period of 75 days (July 15 to September 30) and a maximum daily strand of 622 fry/day, projected that a total of 46,650 steelhead fry would be stranded on gravel bars. This value will vary depending on a number of factors some of which vary naturally and others that are undefined. These factors include the actual daily operation of Gorge Powerhouse, adult escapement, egg-to-fry survival, the amount and type of gravel bars which changes dynamically from year to year, the amount of observer error, predation on fry stranded on gravel bars, and the amount of gravel bar stranding that actually occur in the upper study reach (Reach 3). The only one of these variables that can be addressed is adult escapement. Based on data provided by Washington Department of Wildlife, the escapement of wild steelhead into the Skagit River during the spring of 1985 was average, rather than low or high. The number generated to represent the magnitude of the problem is more of an index value and to determine an absolute number the factors described above would have to be accounted for. Some of these factors would have the affect of raising the stranding total (observer error) and other would likely decrease the total (use of actual daily operation). At this point in the discussion it is important to reflect on the purpose of this exercise; to determine the significance or magnitude of the stranding problem. The number generated is of very little importance, but its order-of-magnitude is worthy of some thought. This number was derived to show that tens-of-thousands of fry are affected, not several orders of magnitude above or below this level. Within this context the significance of steelhead stranding on gravel bars can be weighed.

Perhaps the following example might provide some additional perspective regarding the impact of gravel bar stranding on steelhead fry within the order of magnitude suggested by this investigation (46,650 fry stranded). A simple and unqualified back-calculation can be used to represent how many adult fish would be required to produce 46,650 steelhead fry. If we assume an egg-to-fry survival of 30% and that each steelhead female produces 6,500 eggs then it would take approximately 24 female steelhead to replace lost fry. This example is obviously over-simplified but does provide a means for defining the significance of power generation on steelhead in the upper Skagit River.

c. Spring Gravel Bar Stranding

The following discussion reviews and interprets the results of the analysis of the biological and physical factors studied that may have an affect on gravel bar stranding by chinook, pink, chum fry and steelhead juveniles.

(1) Biological Factors

For fry to be stranded on gravel bars they must first be present in areas affected by downramping. Secondly, once present they must occupy gravel bar habitat that dewaters. Once these requirements are met there are additional biological factors that determine vulnerability to gravel bar stranding that include fry species, and fry age/size. Each of the four fry species studied stranded at different rates, that is to say that there were significant differences between the vulnerability of each species to gravel bar stranding. The analysis results indicated that pink and chum salmon were far more vulnerable than steelhead relative to the chinook fry stranding rate. Pink fry were found to be 10-13 times and chum were 2-43 times more vulnerable than chinook. Steelhead juveniles, on the other hand, were 1.6-2.5 times less vulnerable than chinook fry. Even though chinook were not as vulnerable to gravel bar stranding as pink or chum fry, they accounted for most of the stranded fry because their abundance in gravel bar habitat is much higher than any other species. Pink fry with relatively low abundance were able to account for a large portion of the fry stranded because they are 10 times more vulnerable than chinook. That is to say that their "rate of stranding" is much higher than chinook fry. Likewise, chum salmon fry were far more vulnerable to stranding than chinook, 2 to 43 times more vulnerable. Steelhead juveniles (fry that had over-wintered) as predicted by the results of the summer/fall gravel bar stranding study were far less vulnerable to gravel bar stranding than any other species of salmon fry in the study area. This is quite understandable since steelhead become progressively less vulnerable with size/age. Size/age related changes in salmon fry gravel bar stranding vulnerability could not be evaluated because the fry did not grow appreciably during the 30-day field study period. This was because chinook fry remain in the study area only a short while before outmigrating while pink and chum fry upon emerging from the gravel quickly move out of the area before growth can be achieved.

(2) Physical and Hydrologic Factors

The list of physical and hydrologic factors that could have some influence on gravel bar stranding goes beyond those studied by R. W. Beck and Associates and past researchers. However, the factors included in our studies were selected on the basis of (a) review of past studies; (b) review of 1985 steelhead stranding studies; (c) importance to or affected by hydro operations; (d) suggestions by the Skagit River Standing Committee; and (e) measurability. The statistical analyses presented in Section VI - Results of the Spring 1986 Gravel Bar Stranding Study, identify the combinations of factors and levels within factors where gravel bar stranding of fry shows significant sensitivity. Unlike the summer-fall steelhead fry gravel bar stranding study a large portion of the stranding counts were zero which may have had some effect on the study outcome in terms of biased counts, etc., and may also have affected the analytical results. It is important to bear in mind that the general conclusions of the analysis were reconfirmed when subsets of the data containing few zero counts were analyzed. The data and results given form the basis for a much larger task of synthesizing this information into a comprehensive understanding of the processes involved in fry stranding. The predictive matrices presented here are a first step in this direction. The following provides some general comments for each of the factors examined in this study.

(a) Day Vs. Night Downramping

An experiment designed around a paired t-test was completed by Rod Woodin, a Washington State Department of Fisheries biologist, in 1981-83 to determine if downramping time (dark vs. light) has any effect on gravel bar stranding of salmon fry. The results of his experiment clearly indicate that salmon fry stranded more frequently when downramping occurs during daylight than darkness. (See Section VII for greater detail.)

(b) Gravel Bar Slope

The slope of a gravel bar determines the distance a fry at waters-edge must travel to escape gravel bar stranding. This is the "distance" component of the gravel bar dewatering mechanism. The smaller the gravel bar slope the greater horizontal distance a fry has to travel to avoid stranding for a given change in river stage. As gravel bar slopes increase the distance a fry must travel to remain at waters-edge decreases with a constant downramp stage change and beginning flow. It is very likely that a fish the size of the fry studied do not feel uncomfortable in very shallow water since they need only a fraction of an inch of depth to remain completely submerged. If, for example, on a gravel bar with a slope of 1% a fry stays at waters-edge as many seem to do, that fry may be in trouble by the time it senses that the water depth becomes too shallow. As the water continues to recede the fry has only a small amount of time to react and make the decision to move toward mid-channel. On a shallow gravel bar the distance to a safe depth is far greater than with a steep gradient. The greater the distance the greater the potential risk, since a decision must be made each time the fry changes position to adjust to the receding waterline. This is compounded by the reduced escape time associated with a shallow gravel bar. For any combination of downramp stage change the water will always recede more quickly on a shallow gravel bar than on a steep one which means that a fry must not only travel farther to escape but faster.

(c) Downramp Amplitude Fluctuation

Two separate hypotheses were tested with regard to the effect of downramp amplitude fluctuation on gravel bar stranding. Two amplitudes (2,000 and 4,000 cfs) levels were tested. The ANOVA in Table 35 failed to reject the hypothesis that there was no difference between stranding due to amplitude. The hypothesis that stranding was proportional to amplitude was also rejected. These results are counter to what may have been expected, especially in light of opposite results of the same tests for the summer/fall steelhead fry. The level of a particular amplitude fluctuation of a downramping event controls the amount of dewatered gravel bar. Prior to these studies it was reasonable to assume that the amount of stranding would have been associated with the amount of gravel bar dewatered (the more gravel bar exposed the more stranding assuming all other factors remain unchanged). This is in fact what was observed with steelhead fry in the summer/fall studies, but apparently the relationship does not hold for salmon fry during the spring months. Stranding, therefore did not appear to be influenced by downramping amplitude (within the testing range). Even when zero observations were reduced by using the highest stranding totals (0-5% slopes) there was still no significant difference between the number of fry stranded with 2,000 versus 4,000 cfs amplitudes.

(d) Downramp Endflow

The downramp endflow is the flow measured at the Marblemount stream gage that represents the end of a downramp amplitude fluctuation. During the study design phase there was considerable concern by the Washington State Department of Fisheries (WDF) regarding the potentially harmful effects of downramping below 3,500 cfs at the Marblemount gage. It was felt that certain parts of the stream channel represented "critical habitat" that if dewatered could cause higher levels of stranding than seen above this point. For this reason two separate downramp endflows were chosen to test this hypothesis, one above the assumed critical area (3,500 cfs) and a second 500 cfs below that level (3,000 cfs). The results of the statistical tests showed no significant difference under any testing condition. (See Tables 31-34.) These results appear to support the thought that within the range of flows studied, the ending flow of a downramp event has no bearing on the numbers of fry stranded, down to a 3,000 cfs endflow. Below this endflow level it is unknown whether this relationship holds true.

(e) River Location

The term "river location" is used in the context of distance from the source of the flow fluctuations. In this case the Gorge Powerhouse represents the closest river location to the fluctuation source and Rockport Bar the farthest. The results of the analysis showed that the river location effect was most pronounced when ramping rate was 5,000 cfs/hr or when only small substrate sites were included in the analysis. As described in Section II - Hydrology of the Skagit River, the effects of flow fluctuation are moderated as a positive or negative wave moves downstream. Thus the time required for a downramping event to pass a downstream point on the river would be much longer than for an upstream location. Likewise, the hydrologic effect of a given ramping rate is much stronger upstream than downstream. Because of this "river location" effect on some hydrologic factors there are changes in the magnitude of stranding that are controlled by the location of the gravel bar. An example of this shown by Figure 44 (Section VI) where the effect of a 5,000 cfs/hr ramp rate is greater than for a 1,000 cfs/hr rate regardless of river location, but the magnitude of the average stranded changes between river location because the effect of the ramp rate is reduced by the time it reaches the lower reach. In effect, a 5,000 cfs/hour ramping rate released at Newhalem can be measured at the Marblemount gage as only a 2,500 cfs/hr ramp rate because of the hydrologic factors mentioned earlier. This same relationship applies to gravel bar slope.

The upper reach of the study area was not incorporated into the study design. The predictive matrices constructed to determine the magnitude of the stranding problem applied and used the stranding rates calculated for the middle reach to the upper reach (Copper Creek to Newhalem) which was not studied. The importance of river location indicates that the upper reach may be more strongly affected than the middle reach due to its close proximity to the Gorge Powerhouse. However, there was no logical process for determining what this effect (measured as stranded fry) may have been.

(f) Downramping Rate

Two downramping rates were used and the difference between them tested significant under conditions that tended to maximize stranding (Table 40). The 5,000 cfs/hr ramping rate stranded significantly more fry than the 1,000 cfs/hr rate. This relationship was amplified in the middle reach where any effects due to ramp rate would be expected to be most pronounced due to river location (Figure 45). The average number of fry stranded per 200 feet of gravel bar was much higher in the middle reach with a 5000 cfs/hr ramping rate than in the lower reach. Also, as expected, the average fry stranded on gravel bars with a

0% to 5% slope was much higher with a 5,000 cfs/hr than the 1000 cfs/hr ramp rate. The ramp rate determines how much time a fry has to avoid stranding, the higher the rate the less time a fry has to make each of the position changes probably required during each downramp event. An accelerated ramp rate was tested during the summer/fall gravel bar stranding study, part of which involved a 500 cfs/hr ramp rate. Those results indicate that somewhere between 500 and 1,000 cfs/hr the rate of steelhead fry stranding may drop off and above 1,000 cfs/hr up to 5,000 cfs/hr there is little or no change in stranding rates. No ramp rate below 1,000 cfs/hr was tested on salmon fry and because salmon fry responded differently than steelhead fry to some of the testing parameters it would be dangerous to assume that stranding rates would drop below 1,000 cfs/hr.

(g) Substrate

The two levels of substrate, less than and greater than three inches, tested significant under conditions which maximize stranding (Tables 35 and 41). The relationship between substrate and other factors such as ramp rate, bar slope, and river location were variable and complex. Without providing a logical explanation for the results, it was clear that for gravel bars with slopes between 0 and 5 percent, those with small substrate strand many more fry than those with large substrate. Also, in the middle reach, where effects were more pronounced because of this reaches upstream location, gravel bars with small substrate tended to strand significantly more fry than large substrate. In the lower reach this relationship did not hold.

(3) Magnitude Of Salmon Fry Gravel Bar Stranding

The spring 1986 gravel bar stranding studies produced data on gravel bar stranding of salmon fry in the Skagit River between Copper Creek (River Mile 84.0) and Rockport (River Mile 67.5). These data estimate the typical number of fry stranded on gravel bars within this stream reach within the range of observed operational flows and within the limits of the study. The data did not account for gravel bars located between Copper Creek and Newhalem. However, the gravel bars in the upper stream reach were inventoried with respect to bar type (slope and substrate) and length. The average number of fry stranded on these bars was estimated by assigning stranding rates derived from the middle stream reach. The data did not account for two other possible sources of error. Observer error during the field study would underestimate stranding as would unaccounted for predation on stranded fry. Predation on stranded fry during the spring months certainly could account for some error, however the fry stranded-/bar area rate were so small compared with those for steelhead in the summer-/fall that it seems unlikely that a predator could maintain a high enough recovery rate to justify routine gravel bar searches.

A total of 19,512 fry would be stranded using the "high side" scenario described in Section VI of this report. This number was derived during a pink fry emergence year so it is likely that this estimate for a non-pink year would be lower since there would be less fry in vulnerable areas. Even if chinook fry made up the difference in fry population numbers, less fry would be stranded during the season since chinook are not as vulnerable to stranding as pink fry (10-13 times less vulnerable). Adult escapement during 1985 for summer chinook, chum, and coho were average when compared with escapement between 1975-1985.

The escapement of pink and spring chinook were considerably higher than the 10-year average. This analysis considered fry abundance of these species to be normal. The accuracy of this number is highly debated given the unaccounted-for error, but the magnitude of the number is what should be considered. The purpose of the exercise was to determine the magnitude of the problem (i.e., are seasonal fry stranded numbers on the order of 100's; 1,000's; 10,000's or 100,000's) not the absolute number of fry stranded. The number generated, assuming that it is within an order of magnitude, indicates that salmon fry stranding from the spring of 1986 were in the low tens to hundreds of thousands.

The following example provides another means for determining the magnitude of power generation on salmon fry. If we assume that an egg-to-fry survival rate of 30% and that each salmon female produces on the average of 4,500 eggs, then it would take approximately 15 females to replace the salmon fry lost to gravel bar stranding.

4. INTEGRATION OF RESULTS

The three major studies were conducted over an eighteen month time period generating a vast amount of field data which contributed to an extensive database from which the results presented in this report were drawn. The matrix in Figure 52 presents collectively the general results of these studies which provides a means for comparing the results of one study or season with another. The matrix presents the parameters (factors) in terms of their importance to pothole trapping and stranding and gravel bar stranding for the spring and summer/fall (summer) seasons. The factors are arranged by three factor types; physical and spatial factors (bar slope, substrate, etc.), biological factors (fish species, etc.), and downramp parameters (downramp amplitude, etc.). The matrix addresses potholes and gravel bars individually as well as collectively (as a population).

TABLE 49 - Matrix of Factor Importance to Pothole Trapping and Stranding and Gravel Bar Stranding for the Spring and Summer/Fall Seasons Arranged by Three Parameter Types.

	POTHOLES				GRAVEL BARS	
	SPRING		SUMMER*		SPRING	SUMMER
FACTORS	Trap	Strand	Trap	Strand		
A. Physical And Spatial						
Stream Reach	YES/2	n/a	YES/2	n/a	YES	YES
Pothole Type (3)	YES	YES	YES	YES	n/a	n/a
Connection Flow	YES	n/a	YES/2	n/a	n/a	n/a
Dry Flow	NO	YES	NO/2	YES	n/a	n/a
Pothole Cover	YES	NO	YES	NO	n/a	n/a
Substrate Size	n/a	n/a	n/a	n/a	YES/6	YES/6
Gravel Bar Slope	n/a	n/a	n/a	n/a	YES	YES
B. Biological						
Fish Species	YES	n/a	YES	n/a	YES	YES
Calendar Date	YES	n/a	YES	n/a	YES	YES
C. Downramp Parameters /1						
Pothole Overflow	YES	n/a	UNKNOWN	n/a	n/a	n/a
Beginning Flow	YES	n/a	YES	n/a	NO/9	NO/9
Ending Flow	YES	YES	YES	YES	NO	NO/8
Ramp Rate	NO	NO	UNKNOWN	NO/4	YES	NO/5
Amplitude	YES	YES	YES	YES	NO	YES
Time (Day/Night)	NO/9	n/a	UNKNOWN	n/a	YES/7	NO
Short-Term Flow History	NO	NO	UNKNOWN	NO	NO/9	NO/9
Long-Term Flow History	YES	NO	UNKNOWN	NO/4	NO/9	NO/9

* No formal studies conducted
n/a Not applicable

(1) Factors that are either partially or completely controlled by SCL operations.
(2) 80% of all potholes located in the lower reach
(3) Pothole size, depth, streambank location, drainage characteristics.
(4) Assumption that results from spring pothole study would apply to the summer/fall pothole season.
(5) Higher ramp rates (5,000 cfs/hr) generally stranded higher numbers of fish and ramp rates of 500 cfs/hr may strand less fish. These results were not statistically founded.
(6) Substrate as a factor was statistically significant but with many reverse reactions that were difficult to explain.
(7) These findings were the result of studies and analysis conducted by the Washington State Department of Fisheries.
(8) Assumption that results from the spring gravel bar stranding study would apply to the summer/fall gravel bar stranding season.
(9) These factors were not studied or statistically tested.

Physical and spatial factors share the common concept that they are not directly controlled or altered by Seattle City Light operations. For example, the spatial location of a particular gravel bar with respect to Gorge Powerhouse can not be altered unless the powerhouse location were to be physically moved. These factors however, are all very dynamic over time. The slope of a specific gravel bar changes (perhaps only slightly) as influenced by high-water events is an example of this. These factors can be categorized as difficult to control or manipulate. Some of these physical and spatial factors play an extremely important role in fry trapping and stranding in potholes and stranding on gravel bars but would be difficult or in some cases impossible to alter to minimize trapping or stranding. A good example of this is the following. Nearly 80% of the fry stranding during the summer/fall season occurred on gravel bars with slopes between 0-5%. If the amount of this type of gravel bar could be reduced or eliminated the result would be a dramatic decrease in stranding. This represents a factually correct approach that is not viable because there is not practical way of altering the slopes of gravel bars on the Skagit River. The same applies to the other factors in this category with the possible exception of pothole type, which basically refers to the size and depth of individual potholes. It is conceivable that the size and depth of a single pothole or group of potholes could be altered by filling them in with existing substrate materials. Once done this would alter the dry flow and potentially the connection flow of the pothole. This approach would be only a temporary measure since the pothole population is constantly changing from season to season.

The fish species and calendar date are factors that are of biological origin. Specifically, certain fish species are present in the spring verses the summer/fall season and some species are more vulnerable to stranding than others. These factors do influence stranding as shown by the results of the studies but they can not realistically be altered or controlled to reduce stranding.

Downramp parameters represent the final category of factors that were studied to determine their effect on trapping and stranding. This category of factors differs from the others because they are mostly a function of hydropower operations and are subject to human control. For example, the time (day vs. night) of a downramp can be controlled by Seattle City Light.

It is logical to assume that the eight downramp factors listed in Table 49 also represent the one category of factor type that could realistically be manipulated to modify the levels of trapping and stranding. It is appropriate to draw attention to this category of factors in Table 49. It is important that these factors and their importance to trapping and stranding in potholes and stranding on gravel bars be examined closely since a variation of one factor may be capable of reducing pothole trapping and stranding but may have a reverse effect on gravel bar stranding and perhaps spawning or redd dewatering.

Fish behavioral responses are another category of factors representing an important component of the trapping and stranding phenomena that were not studied statistically but play an important role in the overall mechanism of trapping and stranding. The results of the fry residence time in potholes by Troutt (Appendix E) and Ladley's study of recruitment of fry into empty potholes and the concept of longterm flow history (Appendix R) were the primary contributions to behavioral research pertaining to potholes.

Troutts' work showed that most species of fry remain in or return to a pothole for more than one downramp event. The results of Ladley's study showed that fry recruit into empty potholes immediately and that recruitment continues when low downramp beginning flows are repeated. This recruitment process is interrupted by the occurrence of a high beginning flow.

In consideration of the four categories of factors it is essential that each category be kept in perspective. Because the factors within the physical/-spatial and biological categories can not realistically be altered, their relative level of importance is diminished because there is no latitude for change. The objective of any changes would be to reduce trapping and/or stranding rates. Accordingly, the factors that have proven to be of importance and that can also be changed should receive an elevated importance because they have the potential to be altered so as to reduce trapping and stranding.

This evaluation approach suggests that controllable factors of importance merit further discussion. Other factors of importance or non-importance should be considered further only when a significant interaction has been shown with a controllable factor of importance. For example, gravel bar slopes of 0-5% were perhaps one of the most significant (important) factors identified, yet it also is a factor that can not realistically be changed. It is very important that we know how this factor interacts with controllable factors such as ramp rate or amplitude during the spring gravel bar stranding season.

Given the approach outlined above, there are eight factors, all of which fall into the factor category of downramp parameters that merit further consideration since each of these factors can be controlled in differing degrees of magnitude, difficulty and cost. The other factors are of lesser importance since they can not be controlled or manipulated, but as mentioned earlier must not be overlooked because of how each interacts with the eight downramp factors.

A. Controllable Factors

The following discusses each of the eight downramp factors separately and in combination where significant interactions with other factors occur.

Amplitude - this factor has a greater influence over pothole trapping and stranding and gravel bar stranding than any other factor, with the possible exception of gravel bar stranding during the spring season (See Table 49). If daily amplitude fluctuations were eliminated, as in the case of a run-of-the-river system, the majority of the stranding losses would be eliminated without consideration given to any other factors. Even if amplitude fluctuations caused by power generation were eliminated stranding would still not be eliminated entirely since stranding is a natural occurrence on uncontrolled river systems as demonstrated by the results of the surveys conducted on the Sauk River (Section IV). Assuming that amplitude elimination is not possible, it becomes important to understand how the magnitude and pattern of amplitude can be altered to reduce stranding.

The matrix developed for potholes (Figure 16) shows that as the amplitude increases so do the number of potholes that become disconnected and go dry. The results of the summer/fall gravel bar study suggests that stranding increases in proportion to the amplitude. With these results in mind, it is clear that the smaller the range of downramp amplitudes the lower the resultant stranding rates.

On the other hand, the behavioral study conducted by Ladley indicates that fry recruitment into potholes increases when low beginning flows are repeated in successive downramps. Therefore, to avoid increasing the number of fry at risk to pothole stranding while maintaining a reduced range of downramp amplitudes to reduce gravel bar stranding, higher beginning flows would have to be sustained to maintain a pothole overflow level that elicits low trapping rates. If this approach were adopted it should be maintained during both the spring and summer/fall pothole trapping and stranding seasons to provide maximum protection. Another possible variation would be to use this method during the period of peak vulnerability. If adopted for the summer/fall season this protection measure requires the acceptance of the assumption that the pothole overflow/fry trapping relationship holds true for the summer/fall season.

Another consideration that will require careful thought would be the possible reduction in preferred rearing habitat for newly emerged fry brought about by higher beginning flows. With higher beginning flows it is conceivable that suitable rearing habitat may be reduced because of full channel flow which may possibly eliminate important types of waters-edge habitat. During the field studies it was apparent that a large portion of the newly emerged fry occupied waters-edge habitat because of reduced water velocity. This type of habitat may be reduced because the river will be flowing closer to full channel. This approach could also encourage steelhead to spawn at higher flows which in turn would require higher incubation flows to avoid redd dewatering.

Another possible long-term effect of this scenario could possibly be an upward shift in the distribution of pothole connection and dry flows resulting from the long-term effects of higher flows. The formation of potholes is thought to be primarily a hydraulic process. Although this is unproven, it is logical to assume that new potholes would be created higher on the streambank if a pattern of higher flows were instituted.

If the upper parts of most gravel bars have higher slopes during full channel flow a positive side-effect might be a decrease in gravel bar stranding if gravel bar slopes are increased from the 0-5% to the >5% range. There is a dramatic decline in stranding on gravel bars with slopes greater than 5%. This speculation assumes that the shoulder of the streambank at full channel is steeper than what might be present at lower, more typical flows, similar to those tested.

Another consideration associated with the concept of smaller amplitudes with higher beginning flows would have to be the cost and/or benefit(s) to power generation.

There are other controllable factors such as downramp rate and time that need to be discussed in conjunction with amplitude due to their interactions with, and potentials for reducing stranding beyond the amplitude scenarios discussed above.

Ramping Rate - The speed or rate by which the flows are reduced defines the process or factor that these studies investigated and reported on. The reverse process is termed upramping, the speed or rate by which flows are increased. Upramping was not studied. Upramping is assumed to be of little concern to trapping and stranding of fish. Downramping on the other hand was studied because it was considered to be one of the key factors influencing trapping and stranding.

The results of our studies suggest that ramping rate does not influence trapping or stranding in potholes within the range of rates studied.

The analysis for the spring gravel bar stranding study determined that ramping rate was a significant factor. The higher ramping rate (5,000 cfs/hr) stranded significantly more fry than the lower ramp rate (1,000 cfs/hr). A similar analysis of the summer/fall gravel bar stranding data determined that ramping rate was not a significant factor although the average stranding rates were slightly higher when the higher ramping rate was used (see Figure 26). Other data from the summer/fall gravel bar stranding study was used to examine and accelerated ramp rate and suggested that stranding rates were reduced when downramp rates of 500 cfs/hr were used.

If ramping rates were reduced, the results indicate there would be no net change in the number of fry trapped or subsequently stranded in potholes during either of the seasons studied. During the spring season gravel bar fry standing could be reduced if the ramping rates did not exceed 1,000 cfs/hr during the peak vulnerability period. We do not know if stranding rates increase linearly between 1,000 and 5,000 cfs/hour or whether above a threshold level stranding rates increase from the 1,000 cfs/hour rate to the 5,000 cfs/hour rate. If some ramp rate between the two levels studied were used, the resulting stranding levels can not be predicted in that they may strand at the 1,000 cfs/hr level or just as easily at the 5,000 cfs/hr level or somewhere in between. Short of specifically studying other levels of ramping rate there is no dependable means of determining stranding levels at other ramp rates from our data.

Further insight into this matter was drawn from Figure 45, which is a histogram showing the effects of downramping rate on salmon fry stranding at different levels of other testing factors. We discovered during the pothole study that ramping rates created at the Gorge Powerhouse are dampened by the time they arrive at Marblemount. In general, the downramp rate was reduced considerably by the time it reached Marblemount. From Figure 45, the stranding rate of 1.19 fry/200 feet of gravel bar with a 5,000 cfs/hr downramping rate in the middle reach was reduced to .48 fry/200 feet of gravel bar in the lower reach. Because distance dampens the ramp rate and if the ramp rate becomes only 50% of the original ramp rate by the time it arrives at the lower reach, then the estimated 2,500 cfs/hr ramping rate has only a slightly higher stranding level (.48) than a 1,000 cfs/hr ramping rate (.44 fry/200 feet of gravel bar). This speculative example merely attempts to point out that ramp rates less than perhaps 2,500 cfs/hr may result in stranding levels nearer the 1,000 cfs/hr than the 5,000 cfs/hr rates.

During the summer/fall gravel bar stranding season the statistical results showed there was no significant difference in fry stranding rates between the 5,000 and the 1,000 cfs/hr ramping rates. However, in all but one testing combination the 5,000 cfs/hr ramping rate had slightly higher stranding rates than with 1,000 cfs/hr ramping rate (Figure 26). The results of the statistical tests determined that the measured stranding levels do not differ greatly enough to be considered significantly different. With these results in mind it is probably safe to suggest that this factor, compared with others, may be of much less importance to stranding of fry during the summer/fall season within the range of ramp rates tested.

Although not formally studied or tested, evidence suggests that ramping rates of 500 cfs/hr may contribute to lower stranding rates. The results indicate that when ramping rates are reduced to 500 cfs/hr, fry may be capable of following the waterline down the gravel bar with greater success. We assume that the reduced speed of the falling waterline is slow enough that even recently emerged fry may be able to avoid stranding with more regularity. Because this was not formally tested, it is suggested that consideration be given to the reduction of ramping rates to this level during the summer/fall season if power generation is not compromised greatly. The 500 cfs/hr rate was only studied during the summer/fall gravel bar study. It is not known whether similar results would be determined for the spring season.

One possible side-effect of a 500 cfs/hr ramping rate is that by slowing down the receding waterline there is greater opportunity created for fry to locate and occupy potholes. Faster rates afford fry less time to locate potholes as the waterline recedes. With the exception of this possibility ramping rate is thought to have no effect on the number of fry trapped and stranded in potholes during the summer/fall season.

Pothole Overflow - This factor appears to be a key component in determining pothole trapping numbers during the spring season. Although not studied, it is assumed to be of equal importance during the summer/fall season. If an emphasis is placed on reducing the total number of fry trapped in potholes (fry at risk to stranding) then it becomes necessary to avoid repeating downramps with low beginning flows in the range of 4,500 to 5,000 cfs. If this approach is taken it discourages the buildup of fry in potholes. Alternately, if a series of low beginning flow downramps can not be avoided it should be followed by a high beginning flow downramp to flush recruited fry from potholes before low ending flows are used. If a low ending flow occurs before a high beginning flow can flush fry from potholes many more fry will be vulnerable to stranding.

Downramp Time - The time of downramping was tested for its possible effects on gravel bar stranding of fry in both seasons. During the spring season downramping primarily affects salmon fry. The results of tests conducted by the Washington State Department of Fisheries has shown that the time of downramping has a significant affect on the numbers of fry stranded on gravel bars. Approximately seven (7) times the number of fry are stranded when any part of the downramp occurs during daylight as compared to an identical downramp conducted entirely in darkness. The results of the summer/fall gravel bar stranding study, effecting primarily steelhead fry, strongly suggest that the time of downramp has no effect on the numbers of fry stranded.

Given these results it is suggested that daylight downramping should be avoided during the spring season which is presently in force under the Interim Flow Agreement between Seattle City Light and Joint Resource Agencies. It is further suggested that the avoidance of daylight downramps by Seattle City Light be waived during the summer/fall season because this factor is probably of no importance in reducing the number of fry stranded on gravel bars.

The day versus night downramping factor was not part of the study design for pothole trapping and stranding investigations. We would speculate that if a response could have been detected it would have been in the form of the number of trapped fry in potholes, but not stranded. Without data it is difficult to predict how this factor would effect trapping in potholes. Without further study it may be safest to assume that if there is a measurable effect it would be similar to the response detected for gravel bar stranding for the two seasons. Using this assumption it would still be advisable to operate as suggested above.

If a limited amount of daylight downramping is necessary during the spring months and can be anticipated and planned for it would be important to minimize the response level of other factors to minimize stranding. For example, to minimize gravel bar stranding the ramping rate and amplitude should be held to a minimum and for pothole trapping a large pothole overflow the day before the daylight downramp would hold the trapping rates down.

Long-Term Flow History - This appears to be one of the key factors affecting the number of fry trapped in potholes, which ultimately determines the number of fry stranded. This factor was first discovered during the analysis of the data from the pothole study of 1985. The importance of this factor was re-confirmed by the results of study on recruitment of fry into potholes during the spring of 1986. The influence of this factor is assumed to apply to the summer/fall season although there is no data to support this speculation.

This factor can be manipulated to reduce the number of fry trapped and subsequently stranded by following a series of low beginning flow downramps with a high beginning flow downramp prior to dropping the river flow significantly lower than previous downramps. This type of procedure could minimize the number of fry stranded by flushing most of the fry from the potholes. From a biological standpoint this approach may work but it could be difficult and costly in terms of power generation and may have other constraints as discussed earlier during the amplitude factor discussion.

Long-term flow history is felt to be of no importance to gravel bar stranding since fry are constantly re-adjusting their waters edge position as flows change with fluctuations caused by tributary inflow and power generation.

Short-Term Flow History - This factor was thought to be of some importance to pothole trapping initially. Results from the pothole study, while incomplete, suggest that short-term flow history (a few hours prior to a downramp) is not an important factor to pothole trapping.

There is no apparent reason to believe that this factor has any influence on gravel bar stranding during either season. Short-term flow history does not seem to be of importance to either pothole trapping and stranding or gravel bar stranding.

Downramp Ending Flow - Two levels of downramp ending flow were tested during the summer/fall gravel bar stranding study. The results showed that the ending flows tested were nog important to gravel bar stranding during the summer/fall gravel bar stranding season. This suggests that the area on a gravel bar that is dewatered during a downramp is not nearly as important as the type of gravel bar that is dewatered (slope, substrate and location). Manipulation of this factor would be of no benefit to gravel bar stranding.

Ending flow is an important pothole trapping and stranding factor because it generally determines the status of each pothole in the population at the end of a downramp event. The beginning flow and the amplitude of the downramp are the two other factors that are required to completely define a pothole downramp event in terms of determining which potholes become disconnected and which potholes go dry. The management of this factor for reducing trapping and standing is dealt with above in the discussion on amplitude.

Downramp Beginning Flow - This factor determines the upper limit of each downramping event and within the context of this study appears to be of importance to pothole trapping and stranding. The level of the beginning flow determines which potholes are connected and disconnected at the start of each downramp.

The beginning flow also determines the depth of pothole overflow which is a very important factor in determining the number of fry trapped in potholes. The pattern of downramp beginning flows over a series of downramps is also an important factor because it controls the level of fry pothole recruitment. This factor, and its management is addressed above in the discussion of amplitude. Like ending flow, this factor has no effect on gravel bar stranding.

b. General

Perhaps one of the most interesting results of the studies involves a comparison of the spring and the summer/fall gravel bar stranding studies. The level of the stranding rates reported for each study (fry stranded/200 feet of gravel bar) were quite different. The level of the stranding rates reported for the summer/fall gravel bar study were much higher than those for the spring gravel bar stranding study. It is important to recall that virtually all of the gravel bar sites studied were identical for both studies as were the level of effort applied. The only difference between the two studies were the season, species and fry densities. The later factor, fry density, is assumed to be significantly different due to the greater numbers of salmon verses steelhead adults spawning inside the study area. Salmon fry densities in the spring must be higher than steelhead fry densities in the summer/fall. If fry abundance is higher during the spring season than summer/fall, and if the species are equally vulnerable between seasons then spring stranding rates should have been higher than summer/fall. The opposite actually occurred which may be the result of a difference in species vulnerability between newly emerged salmon and steelhead fry. There was not logical way to evaluate vulnerability difference between newly emerged steelhead and salmon fry because of thier difference in emergence timing. If true, it suggests that chinook salmon fry are much less susceptible to gravel bar stranding than steelhead fry. Also that a higher percentage of the steelhead fry population is affected by gravel bar standing than salmon fry.

The magnitude of the stranding in potholes and on gravel bars was addressed earlier in this report. A very coarse estimation procedure was used to define the approximate magnitude of fry stranding. The procedures used did not account for several factors affecting total stranding. Factors such as observer error and predation on stranded fry could not be evaluated to determine their contribution to total stranding. Inclusion of these factors in the estimation procedures would have increased the total number of fry stranded. Conversely, within the limits of this study it was suggested that the stranding estimates for potholes and gravel bars would over-estimate the total fry stranded. This is because the combination of downramp event variables (ramp rate, amplitude, etc.) used in the estimation procedure caused the highest stranding rates ovserved during the study and do not reflect Seattle Light's actual operational patterns. The high ramping rates and large amplitude fluctuation levels used to make the estimates were considerably higher than the typical daily operational levels more commonly encountered. This conservative approach was used in the estimation procedures to, in part, offset unaccounted for losses due to observer error and predation on stranded fry.

A more accurate measure of stranding magnitude was obtained by using the actual hourly flow data to define each downramp opposed to the techniques described above which assumes a single downramp type (producing the highest level of stranding) that occurs over and over again. This project, called the "Skagit River Fry Stranding Integration Model" was conducted to integrate actual operational patterns during the Interim Flow Agreement period (1981-1987) with estimated relative pothole and gravel bar stranding levels developed from this study (Beck, 1989). What follows is a brief description of results. Further details for this project are contained within the project's final report.

The stranding projections determined by this model should be viewed as relative indices for fry stranding. Observer errors and predation on stranded fry, for example, are not accounted for by the model. The indices reported here are intended to reflect the magnitude of fry stranding under different flow scenarios. The model projects the number of fry trapped and/or stranded in potholes or on gravel bars under actual flow conditions during each of the seven flow-years (1981-1987) using the 1985-86 trapping and stranding data from this report. This approach assumes that fry densities and species compositions remained constant from 1981-87. For example, if SCL operations for flow-year 1982 had occurred during 1985-86, the model projects the outcome.

The estimated total number of fry stranded in potholes and on gravel bars ranged from 11,004 in 1987 to 30,417 in 1982 and averaged 20,751 over the seven-year period (Table 50). These changes in total stranding showed that the high-side estimates developed in this report did over-estimate stranding levels within the limits of the study. The variation in actual flow conditions from year to year was evident as shown by distinct differences between stranding totals from year to year. These results indicate the importance of downramp characteristics on fry stranding and also suggest that stranding can be minimized through measures that shape downramp characteristics.

The spring gravel bar study did show a wide range of susceptibility between salmon fry species. Steelhead are not present as fry, but rather juveniles, during the spring season so their susceptibility could not be determined relative to chinook fry.

Another measure that could be implemented to reduce gravel bar stranding is drawn from the finding that stranding of steelhead and chinook is length/age dependent. Fry of these two species are most vulnerable when newly emerged from the gravel and become less so with age and growth. Since these two species represent the bulk of the total fry stranded it may be prudent to apply the mitigating measures described during the period of peak emergence. Emergence timing could be predicted using the SCL Temperature Unit Model and confirmed by monitoring fry abundance in the field.

TABLE 50

TOTAL ESTIMATED NUMBER OF STRANDED SALMON AND STEELHEAD ON GRAVEL BARS AND IN POTHOLES BY YEAR AND SEASON

		Spring	Summer	Subtotals	Grand Totals
1981	GB	6,087.9	4,871.6	10,959.5	12,918
	PH	1,958.5	--	1,958.5	
1982	GB	16,222.0	9,783.1	26,005.1	30,417.9
	PH	4,412.8	--	4,412.8	
1983	GB	18,713.8	9,307.9	28,021.7	30,298.3
	PH	2,276.6	--	2,276.6	
1984	GB	10,872.8	4,957.6	15,830.4	17,521.3
	PH	1,690.9	--	1,690.9	
1985	GB	8,383.9	9,300.4	17,684.3	20,441.0
	PH	2,756.7	--	2,756.7	
1986	GB	14,349.5	5,885.4	20,234.9	22,660.8
	PH	2,756.7	--	2,425.9	
1987	GB	6,073.1	3,908.7	9,981.8	11,004.3
	PH	1,022.5	--	1,022.5	
Histor.	GB	11,529.0	6,859.0	18,388.0	20,751.0
Average	PH	2,363.0		2,363.0	

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